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PRINCIPLES OF
PLANT GROWTH

TEXTBOOK OF GENERAL BOTANY

For Colleges and Universities. By Richard M. Holman, Associate Professor of Botany in the College of Letters and Science of the University of California; and Wilfred W. Robbins, Associate Professor of Botany in the College of Agriculture of the University of California. 590 pages. 6 by 9. 374 figures. Cloth, net $4.00.

LABORATORY GUIDE FOR A COURSE IN GENERAL BOTANY

By Lee Bonar, Richard M. Holman, and Lucile Roush, all of the Department of Botany of the University of California. 106 pages. 6 by 9. Cloth, net $1.25.

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PRINCIPLES OF PLANT GROWTH

AN ELEMENTARY BOTANY

BY

WILFRED W. ROBBINS

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PREFACE

THE object of this book is to present in non-technical language some of the fundamental principles of plant growth. It aims to answer questions which have come to the attention of the writer from farmers and others interested in the growing of plants. No single book, even of large proportions, could include the subject matter which would answer fully the many queries in the minds of growers concerning special plants or crops. There are, however, certain general, basic principles of plant growth, and certain important facts about plants, which, if understood by the grower, will help him to recognize and at least partially solve many of his specific problems. It is not essential that the grower should have a knowledge of the detailed structure of plants; but he should know what work is carried on by the different parts, and how soil, water, heat, fertilizers, cultural methods, and other factors influence the plant.

That there is need for such information is evidenced by the fact that in almost all books dealing with special crops the authors consider it necessary to include one or more preliminary chapters of purely elementary botany. They realize that the reader will not fully understand the special matter pertaining to the crop, unless he has fresh in his mind knowledge of certain essential principles of plant behavior.

This book is so designed as to make it useful as an elementary text in secondary schools. Smith-Hughes high schools, particularly, have expressed a desire for a text adapted to their needs, and, in the preparation of this manuscript, the author has had the counsel of a number of individuals who are instructors or supervisors in such schools. Furthermore, the thought has been to give information for the orchardist, the nurseryman, the farmer—in fact, for all those who grow plants and desire to be familiar

with the principles of plant behavior and the various factors which influence this behavior.

Highly valued suggestions and criticisms as to subject matter have been given by the following individuals, to whom the author wishes to express his appreciation: Professors W. H. Chandler, W. P. Duruz, and W. P. Tufts, of the Division of Pomology; Professor F. L. Griffin, of the Division of Agricultural Education; Professor H. A. Jones, of the Division of Truck Crops, and Professor F. H. Viehmeyer, of the Division of Irrigation Investigations and Practice—all of the College of Agriculture of the University of California; Mr. W. C. Morrison, Marysville Union High School; Mr. V. M. Hoffman, Galt Joint Union High School; and Professor G. A. Schmidt, of the Department of Rural and Vocational Education, Colorado Agricultural College. The author also wishes to record his appreciation to publishers and individuals for permission to reproduce illustrations. P. Blakiston's Son & Co. has kindly granted the use of Figures 6, 13, 18, 19, 28, 29, 30, 31, 32, 33, 34, 35, 37, 40, 41, 47, 50, 64, 66, 111; The Macmillan Co., Figures 96 and 100; John Wiley & Sons, Figures 1, 2, 3, 5, 7, 11, 12, 21, 25, 26, 49, 61, 62, 95, 105, 107, 109, 112, 113, 114, 116, 117, 118, 120, 121, 122, 124, 129, 131, 132, 134. To those individuals who have kindly permitted the use of illustrations, credit is given in the legends. The author is under special obligation to Director C. P. Gillette, of the Colorado Agricultural Experiment Station, for permission to draw upon material in publications prepared by the author and issued by that Station. A number of drawings were made by Ethel Hutton Hyde, to whom the author is grateful for hearty coöperation.

Wilfred W. Robbins.

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PRINCIPLES OF PLANT GROWTH

CHAPTER I

INTRODUCTION

The practice of farming, like that of medicine, or of engineering, is based upon an understanding of a number of fundamental, underlying principles. Success in any one of these fields is in large measure dependent upon one's knowledge of these basic principles, and his obedience to them in practice.

The farmer's chief business has always been and ever will be the raising of plants and animals. Other problems, such as those having to do with marketing, often force themselves upon his attention, and call for much of his time and energy, but his first and most important task is concerned with the growing of plants and animals.

It is the purpose in this book to discuss in non-technical language some of the fundamental principles of plant growth. It is believed that a knowledge of these will enable the grower of plants to proceed with better understanding and, it is hoped, with greater pleasure and profit.

There is great complexity in plant life, and much variation in the structure and habits of plants, but there are certain basic principles of growth which are common to all. In spite of its diversity, there is a unity in Nature. All plants have the same fundamental structure and all have certain processes which are essentially the same. Like animals, plants are living organisms which grow and reproduce.

The Plant and Its Environment.—On the one hand, the farmer is concerned with the **living plant;** on the other, with that complex set of factors we call the **environment.** Rainfall,

moisture of the atmosphere, light, temperature, wind, soil texture, soil water, soil composition, animal pests and plant diseases—these are the chief factors of the environment with which the farmer must deal. A plant, like an animal, is a sensitive living thing. It is influenced by these various factors of the environment. In other words, plants make responses to their environment. The responses of the living plant may be expressed in tons of leaves and stems, in tons of roots, in pounds of seed or grain, in barrels of fruit, or in per cent of sugar, or starch, or acid.

How shall we secure the desired responses of the plant to the particular environmental conditions of our farm? How shall we get the plant to grow in harmony with its surroundings? These are important problems which every farmer faces. First, we must understand something of the structure and functions of the plant. Second, we must have a knowledge of the various factors (climatic and soil) of the environment. And, third, we must know the manner in which the plant behaves under a given set of climatic and soil conditions.

This is a big order. It is asking much. It would appear that the farmer needs a knowledge of many things. As a matter of fact, farming is a complex occupation. Farming has, indeed, become a profession, just as medicine, law, and engineering.

Man's Dependence upon Plants.—We well realize that man is dependent upon plants for his existence. They furnish him, either directly or indirectly, food, fuel, clothing and shelter. He uses them to ornament the home, the lawn, the street, and the park. He derives valued drugs from many. Hundreds of articles used in everyday life are made from wood. He is forced to give his attention to other plants because they are poisonous to him or to domestic animals, or cause disease in animals and desirable plants, or, as weeds, interfere with his agricultural operations. A knowledge of plants, then, becomes of paramount importance in the life of civilized peoples and with the rapidly increasing population of the world, it is becoming more and more necessary that we learn how to "make two blades of grass grow where one grew before." This cannot be

done unless the growers of plants—the farmer, the truck gardener, the orchardist—have a better understanding of **how plants live.**

Abundance and Variety of Plants in the World.—There are few places on the earth's surface where plant life of some form is not found. In both fresh and salt waters there occur many different sorts of plants, some small, or even microscopic, others large and conspicuous. The surfaces of snow fields and ice fields may be colored green or red due to the presence of innumerable minute algae. The upper soil layers abound in plant life, including algae, fungi, bacteria and the roots and stems of those plants which spread their foliage above ground. The air is filled with bacteria, floating spores of fungi, and at certain seasons, light seeds and pollen. Some plants live upon or within other organisms, both plants and animals, deriving from them mechanical support, sustenance, or both. The rocks are clothed with fungi, algae and lichens. Some kinds of plants inhabit the polar regions, and the highest mountain peaks. In the Siberian forest district the temperature frequently sinks to −80° F. Some bacteria and blue green algae thrive in hot springs with a temperature of 170° F. And, too, the driest places support some plant life, as witness the presence of lichens on bare rocks.

There is a marvelous variety of forms and sizes of plants in the world, from minute microscopic bacteria measuring $\frac{1}{36000}$ of an inch in diameter, to the giant Sequoias of California, one individual of which, the General Sherman " big tree," measures 279.9 feet in height and 102.8 feet about its base.

According to one estimate, the number of different species of plants in the world is about 176,000 distributed as follows in the plant groups:

Flowering plants, 103,000 kinds.
Fungi and bacteria, 40,000 kinds.
Algae (pond scums and seaweeds), 14,000 kinds.
Mosses and liverworts, 7500 kinds.
Lichens, 5500 kinds.
Ferns and allies, 3500 kinds.
Conifers, 2500 kinds.

Cultivated Plants and Their Origin.—The plants that we cultivate in our orchards, gardens, and fields are, of course, but a few among the total different kinds to be found in the world. A relatively small number of plants has been brought under cultivation. Primitive man soon discovered that certain plants growing in a wild state about him would furnish him food, and material from which to make clothing and shelter. No doubt, he soon recognized that all the individuals of a given food plant did not yield with equal abundance; and, he also discovered that with care (culture) these food-producing plants would yield more bountifully. And, so, man has selected and cultivated certain of the wild plants. Every year he is adding to his list of cultivated plants and improving those already under cultivation.

We owe much to plant explorers, a number of which have been employed by the United States Department of Agriculture, who have exposed themselves to the discomforts and dangers of travel in out-of-the-way places of the world, to discover and bring back with them plants that show promise of being of economic importance. These plants are tested in the various experimental gardens, or propagating stations established by the United States Department of Agriculture. Among the most familiar introductions are durum wheat, Japanese rice, various alfalfas, the Oriental mango, the date palm, Japanese persimmon, dasheen, avocado, Smyrna fig, soy beans, and Egyptian cotton.

The history of our cultivated plants is indeed an interesting one. It tells of the patient struggles of practical growers and of scientific investigators. Increased crop yields and superior qualities have followed in the track of the knowledge of plants—their structure, their living processes, and their adaptations to various climatic and soil conditions.

CHAPTER II

THE LIVING PLANT BODY AND ITS WORK

We speak of the **human body** as being made up of a number of organs, each with a work to do. There are organs of sight, of hearing, of digestion, of circulation, etc. Just so, we may speak of the **plant body.** It, too, is composed of a number of organs, each having some definite work to perform (Fig. 1). For example, the roots are the absorbing and anchoring organs, the stems are the supporting and conducting organs, the leaves are the water-losing and food-making organs, and the flowers are the reproductive organs.

We realize that if we are to intelligently practice hygiene of the human body we should have an understanding of the reasons for the practice. Most of us do not like to follow a practice, unless we understand the reason for so doing. It is far easier to properly care for our bodies if we know the most important facts about its structure and the work carried on by the various parts. We are better judges of what and how much we should eat if we know of the structure and processes of the digestive system. It is quite impossible to understand how one sees, without some knowledge of the structure of the eye.

Just so, if we are to intelligently practice the growing of plants, if we are to care for them rightly, to give them the proper amount and kind of "food," in short, to understand how plants live, we must know something of the structure of the plant body and the work carried on by the various parts.

The Cell—The Unit of Plant Structure.—If we study with the microscope the structure of the plant organs, we find them to be made up of many small bags or sacs with walls which are usually thin and transparent (Fig. 2). Each of these small,

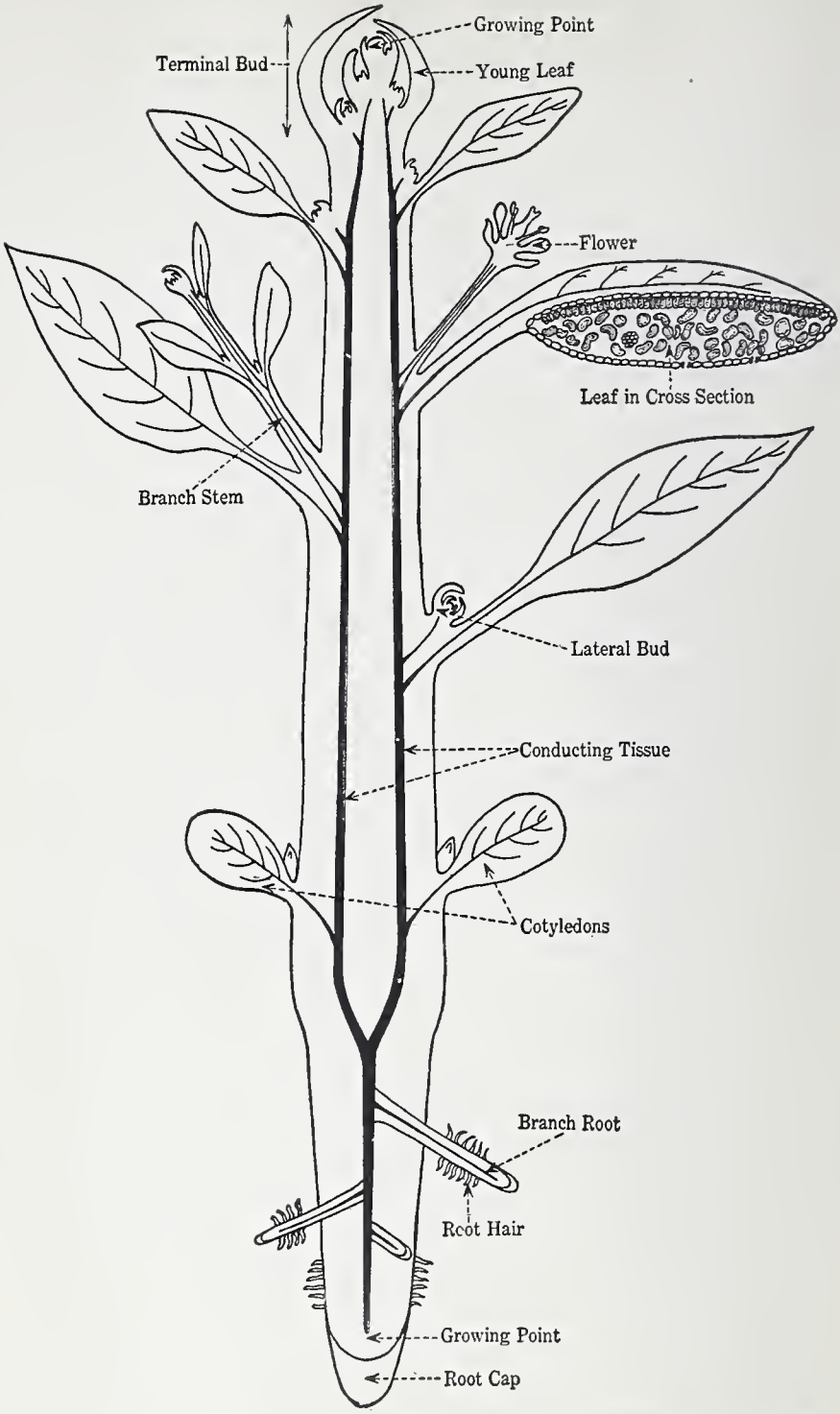

FIG. 1.—Diagram showing the principal organs and tissues of a typical seed plant. (From Holman and Robbins, in *A Textbook of General Botany;* modified after Sachs.)

microscopic sacs or compartments is called a **cell.** Just as a brick house is made up of separate units, the bricks, so is the plant body made of separate units, the **cells.** It is in the cells that all the complex physical and chemical changes of the living body go on. Careful observation under the microscope of plant cells reveals that within each of the cells there is a quantity of a jelly-like substance. This is the **living material** and is called **protoplasm.** The protoplasm of the cell is not of the same structure throughout. A denser mass of living material, the **nucleus,** is usually prominent in the cell. This is a very important part of the cell, taking an active part when the cell divides. In addition to the nucleus, there may be other specialized masses of protoplasm in the cell, known as **plastids** (Fig. 3, F); chief of these are the green plastids (chloroplastids) which are the centers of the process of carbohydrate manufacture. Protoplasm is a mixture of many different chemical compounds, some of which are exceedingly complex.

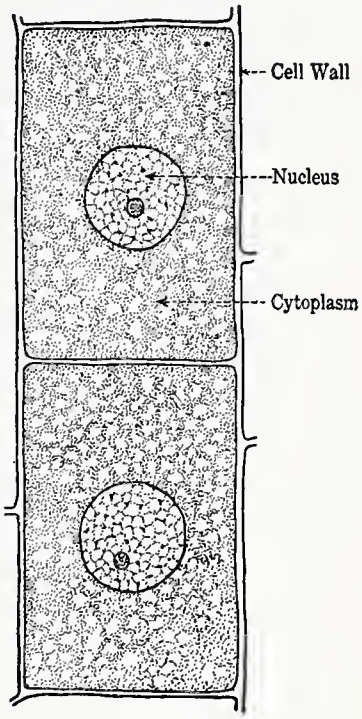

FIG. 2.—Two young cells from the growing point of a root. (From Holman and Robbins, in *A Textbook of General Botany.*)

In addition to the living substance the cell contains much material that is not alive. For example, every cell contains water in which are dissolved various substances that have come from the soil, and certain foods, such as sugar, which have been manufactured in the leaves. The cell also may contain substances such as starch and protein which are not soluble in the water of the cell. **Sap** is the name we apply to the water of the cells **plus** the various substances which are dissolved in the water. The wall about the cell is not alive. It is made up of a

material called **cellulose**, a substance closely related in its chemical composition to starch and sugar. Cellulose, like starch and sugar, is made up of but three elementary substances, carbon, oxygen, and hydrogen. It is of interest to note here, in passing, that cotton, linen and hemp and wood consist of cellulose, and that it is used as a raw material in the manufacture of such substances as artificial silk, celluloid, and gun cotton.

Different Kinds of Cells.—The cells of the plant body vary a great deal in size, in shape, in age, in the kind of material they contain, and the nature of the work they have to do (Fig. 3). It would take about one thousand average-sized sugar storage cells, from the root of a sugar beet, placed side by side to make an inch. Many cells of the plant are box-shaped with either square or rounded corners, others are spherical, and still others are much longer than wide, and with pointed ends. In the growing points of the plant, as in buds and at root tips, the cells are much younger than those found farther removed from these tips. There are cells in the plant body adapted to carry on the different kinds of work it has to do. Some are fitted to carry on the absorption of water and mineral salts from the soil; others carry water, mineral salts and foods from one part of the plant to another; others are specially fitted to manufacture food; many cells act as storage reservoirs of food; and still others are chiefly concerned with reproduction.

Tissues.—The cells of the plant body having these various kinds of work to do are usually grouped together to form tissues (Fig. 3). These tissues are given names describing the functions they perform. For example, there is absorptive tissue, conductive tissue, strengthening tissue, food-making tissue, storage tissue, and reproductive tissue. Any particular organ of the plant such as a leaf, or stem, or root, may be made up of several different kinds of tissues. For example, a leaf possesses conductive and strengthening tissue in its veins, and food-making tissue in the softer parts.

Thus we see that the living plant body, like the human body, is a complex structure, composed of innumerable units, the **cells**, grouped together to form **tissues**, each with a special work to do,

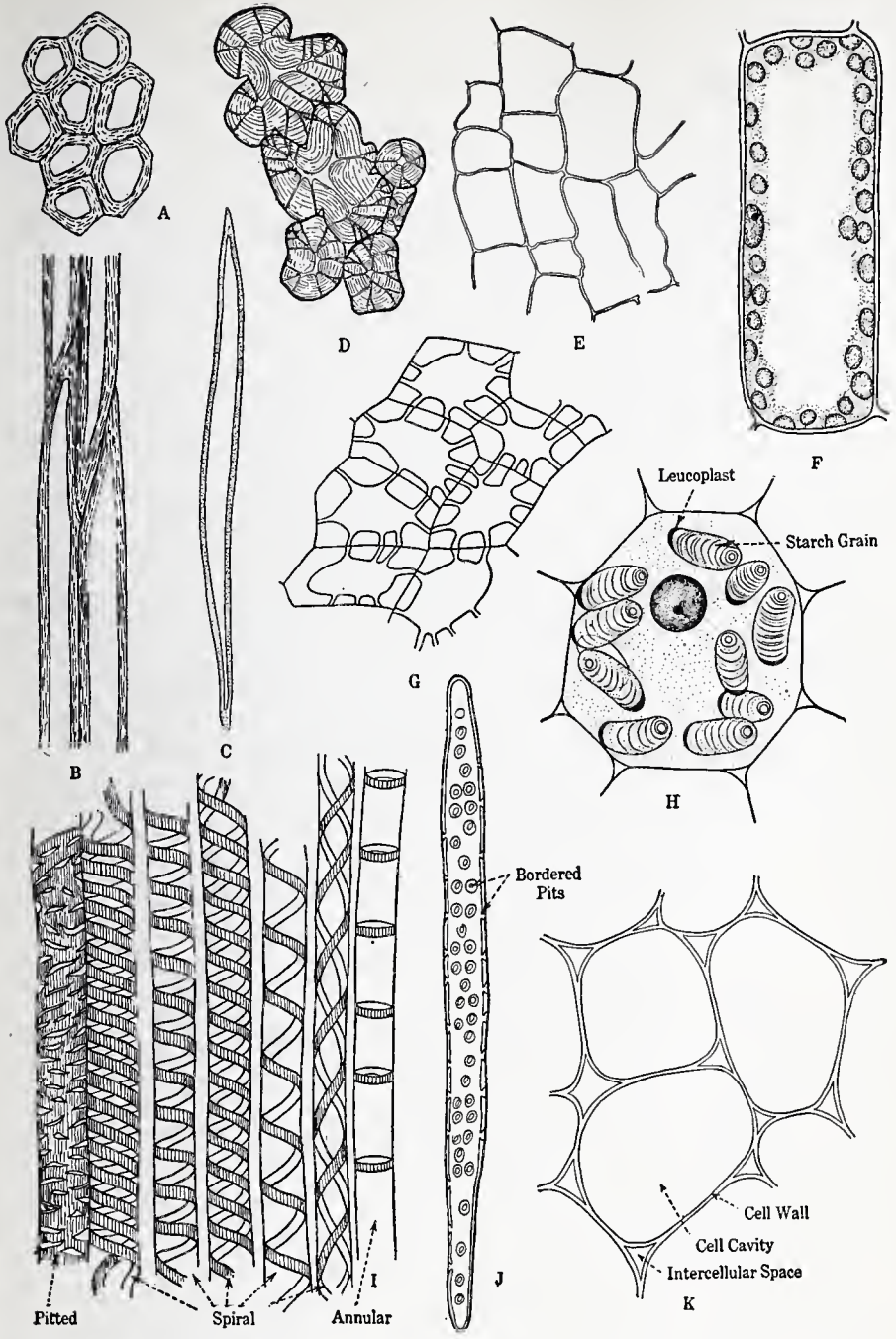

FIG. 3.—Different kinds of cells and tissues. *A*, fibers as seen in cross-section; *B*, fibers as seen in lengthwise section; *C*, a single fiber; *D*, stone cells from the shell of English walnut; *E*, cork cells; *F*, a food-manufacturing cell from a leaf; *G*, thick-walled pitted cells from endosperm of asparagus seed; *H*, starch-storing cell; *I*, different types of tracheal tubes; *J*, a simple pitted tracheid from pine wood; *K*, tissue made of thin-walled cells which fit loosely together. (Except *A*, *B*, *C* and *G*, from Holman and Robbins, in *A Textbook of General Botany*.)

which tissues are in turn grouped to form the **organs** of the plant. We may picture the healthy, living plant as a marvelously constructed body, in which there is a splendid division of labor, with all cells, tissues, and organs working in harmony.

Plants Expend Energy and Do Work.—The reader may question the statement that plants work. It is true that plants do their work much more slowly than animals, but they do nevertheless, **expend energy and do work.** If it were possible to take moving pictures of the plant at work, and to run the film at high speed, we would see the roots twisting and turning, making their way about, and between the soil particles; we would observe the young sprout of the germinating seed straining to lift the load of soil from its path; we would see parts of opening buds moving vigorously; in fact, there would be active movement throughout the plant body; and if we examined the interior of the cells, we would see the living material, the protoplasm, moving in streams from one part of the cell to the other. Plants, like animals, actually do work as long as they are alive, and this work requires a supply of energy.

CHAPTER III

ABSORPTION BY THE ROOTS

In the preceding chapter it was pointed out that the living plant is a complicated structure, with many different parts, each with work to do. In the healthy plant the different parts or organs work together as in a well-ordered machine, each performing its particular duty. And, the proper working of any one organ is very dependent upon the behavior of all other organs. Of course, plants, as animals, have their ills. If some condition is unfavorable to the proper working of the roots, the leaves suffer. On the other hand, if the leaves fail to perform their duties, the roots and other plant parts are hindered in their work.

One of the most important functions of the plant is that of absorbing materials from the soil. What are the absorbing organs? What relation have they to the soil? How long do individual root hairs live? What happens to the root hairs when plants are transplanted? When is the best time to transplant? What chemical substances from the soil enter the plant through the root hairs? Do plants "suck" up tiny particles of soil? What are the chemical elements essential for plant growth? Where do they come from? How do plants differ in their "feeding"? Under what conditions are the root hairs most active and does absorption go on at the most rapid rate? Is a wilted plant capable of growing? How does a strong soil solution kill plants? These are a few of the questions to be discussed in this chapter.

Root Hairs.—In our ordinary crop plants, the very important work of absorbing water and mineral nutrients from the soil is confined to the roots. But not all root surfaces can absorb.

On the slender, thread-like roots are innumerable out-growths, the root hairs, and these are the principal absorbing organs (Fig. 4). In some plants it is almost impossible to see them without a magnifying lens. However, they may stand so thickly on the fine roots as to form a white fuzzy growth. The younger parts of the very fine rootlets which have not become corked over absorb to a limited extent; but in the majority of plants by far the greatest amount of absorption is carried on by the

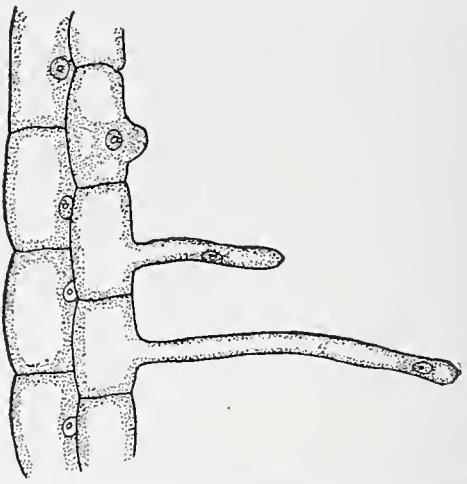

Fig. 4.—A portion of a root showing stages in the development of a root hair. A root hair is an outgrowth of an epidermal cell.

root hairs. Even the fine rootlets soon become covered with a corky layer which is impervious to water.

Transplanting Destroys Root Hairs.—If a plant is transplanted or disturbed in cultivation or at thinning, it wilts. We may see no apparent injury to the roots. However, on closer examination we observe that the root hairs have had their connection with the soil particles broken, and that many of the finest rootlets bearing root hairs are destroyed. The plant does not recover until new root hairs are developed.

It is well known that it is dangerous to transplant young trees, shrubs or vines when they are clothed with leaves and are actively growing. In this condition the plant demands more water than when in a dormant state. If the fine rootlets and

root hairs are destroyed, as is largely unavoidable during transplanting, the demands for water are greater than the roots can supply. Excessive watering will not make up for the loss of roots and root hairs by trees, shrubs and vines transplanted during the growing season. The roots may be surrounded by nearly saturated soil, but in the absence of root hairs, they can not absorb adequate amounts of water. In transplanting it is the usual practice to reduce the water-losing area (leaf surface) by pruning.

Relation of Root Hairs to Soil Particles.—In the growth of the soft, delicate, root hairs, they wrap themselves about and spread over the soil particles coming in very close contact with them (Fig. 5). Thus, they expose a maximum surface to the particles, from which they absorb both water and mineral salts. In a soil that is well drained and contains the proper amount of moisture, the water occurs as very thin films and as wedge-shaped masses at the points of contact of the soil particles, and in this water the various mineral salts are dissolved. Consequently, by growing about the particles, the root hairs place themselves in the best position for getting water and salts.

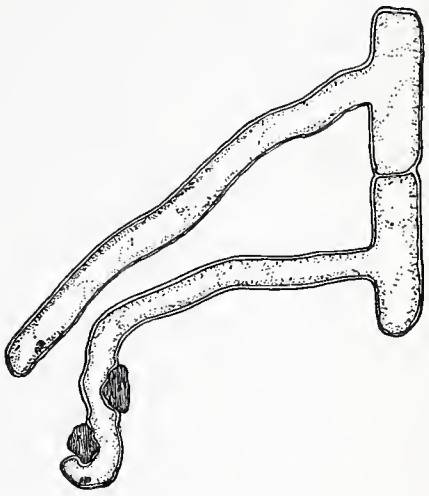

FIG. 5.—Two root hairs showing one which in its growth is flattening out over and partially surrounding soil particles. (From Holman and Robbins, in *A Textbook of General Botany.*)

Root Hairs Increase the Absorbing Surface of a Plant.—A plant with hundreds of thousands of root hairs on its fine rootlets has a tremendous total absorbing surface. The fine rootlets alone, without the root hairs, would have a relatively small total surface. It has been computed that a corn plant with root hairs has an absorbing surface of about 6 times that of one from which the root hairs have been removed.

Duration of Root Hairs.—Root hairs have a very short life. As the rootlet upon which they grow pushes its way through the soil by growth at the tip, new root hairs are continually formed just behind the tip, and the oldest root hairs farther back are constantly dying off. Any one individual root hair lives only a day or so. Thus, there is a constant new supply of rapidly-growing root hairs. Moreover, the roots are continually exploiting new soil regions.

Fig. 6.—Wheat seedling showing soil particles clinging to root hairs; note that the root cap is free of root hairs. (From Robbins, in *Botany of Crop Plants.*

The Structure of the Root Hairs.—The root hair is a tube-shaped body, growing out from a border cell of the rootlet (Fig. 4). In fact, each root hair is a single plant cell with the power to carry on the various life processes. It is a living structure. The living material and the cell sap are surrounded by a non-living wall. The wall is lined on the inside with a very thin membrane of living material. This thin membrane or lining of living material is an extremely important part of the cell, as we shall see later.

Substances from the Soil Enter the Plant Chiefly through the Root Hairs.—It should be emphasized that almost all materials which enter the plant from the soil must pass through the wall and living membrane-lining of the root hair. From the root hair, the absorbed materials are passed on to the other root cells, and from them, into conducting tubes and thence carried to various parts of the plant (Fig. 1).

It used to be thought that plants "suck up" tiny particles of soil, and "feed" upon them. It is now known that the plant is incapable of absorbing solid particles of plant food. All materials taken in by the plant from the soil must be in a liquid state, that is, they must be in solution. Otherwise, they cannot pass,

or diffuse, through the root hair wall and the living membrane which lines it.

Chemical Elements Essential for Plant Growth.—Every plant needs certain chemical elements in order to grow well and come to maturity. Most of these elements must enter the plant in definite chemical combinations. Experiments have shown that there are ten elements which are absolutely essential for plant growth. These are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, and iron. Of course, the plant takes in other elements besides those mentioned, but so far as is known, it can get along without all but the ten just given.

Source of the Elements Essential for Growth.—Of the above ten chemical elements essential for plant growth, carbon comes from the carbon dioxide of the air and enters the plant through the pores of the leaves or openings (lenticels) in the bark; oxygen comes from the air, and enters through the leaf and stem pores, and also through the root, in the water from the soil; hydrogen in the water comes from the soil; and the remainder of the elements—nitrogen, phosphorus, potassium, sulphur, calcium, magnesium and iron—come from the soil, and enter the plant by way of the root hairs. These last seven elements occur in mineral salts. For example, nitrogen occurs in the soil principally as a nitrate, usually of sodium or potassium; phosphorus as a phosphate; potassium chiefly as a chloride, nitrate or sulphate; sulphur as a sulphate; calcium as some lime compound; magnesium as magnesium sulphate or magnesium chloride; and iron as iron phosphate or iron chloride.

Thus we see that, in addition to oxygen, there are two groups of substances entering the plant through the root hairs: (1) Water and (2) mineral salts. The mineral salts of course must be dissolved in water before they can pass through the wall and membrane of the root hair.

"Selective Power" of Root Hairs.—The root hair is surrounded by a soil solution of a number of different mineral salts. These are absorbed at different rates, or at times certain ones are not taken in at all. It is difficult to explain the nature of this

" selective power " of root hairs. However, we know that two plants, wheat and sugar beet, for example, growing side by side on a soil having the same mineral salts, absorb different proportions of these. If we consider two elements, nitrogen and potassium, for instance, the wheat plant absorbs large amounts of nitrogen, whereas the sugar beet uses relatively large quantities of potassium. The fact that plants differ in their chemical composition is evidence of their different " feeding " habits. The reader will find it of interest to look up the chemical composition of certain crop plants.

A Fundamental Reason for Crop Rotation.—This difference in the absorbing power of crops is, of course, a fundamental reason for crop rotation. Different crops need the same mineral elements, but in different proportions. In every soil, normal changes going on there are rendering available the various salts. For example, a soil which has a deficiency of available potash to-day, may have the available supply increased if the soil is not cropped or if placed in a crop which does not demand much potash. Or a soil lacking in available nitrate to-day, may add to this supply if not used up by plants more rapidly than it accumulates in the soil through the usual changes which take place there.

Most Substances in the Root Are Not Lost to the Soil.—It should be pointed out that whereas substances pass from the soil through the root hair membrane into the root, most substances in the root hairs are unable to pass back into the soil. Carbon dioxide, in the ordinary process of respiration of root cells, continually passes from the roots to the soil; and, under certain conditions water also may be lost to the soil. It has been thought by some that under certain circumstances sugar in the beet root passed from the root into the soil. This is not the case. The percentage of sugar in the root may go up and down as a result of different amounts of water in the beet, but the actual ounces of sugar in the root do not become less, except under very unusual circumstances when the stored supply is called upon to make an abundance of new leaf growth. At any rate, the beet root with its root hairs is so constructed as to prevent the movement of sugar from the root into the soil.

The Active Cell is Distended.—The normal, active root hair is swollen and distended like an automobile tire inflated with air. It is filled with water, various mineral salts in solution, and other substances, all of which render it swollen. It does its best work only in this distended condition. If, through lack of water, the plant wilts, the root hairs as well as other cells of the plant, col-

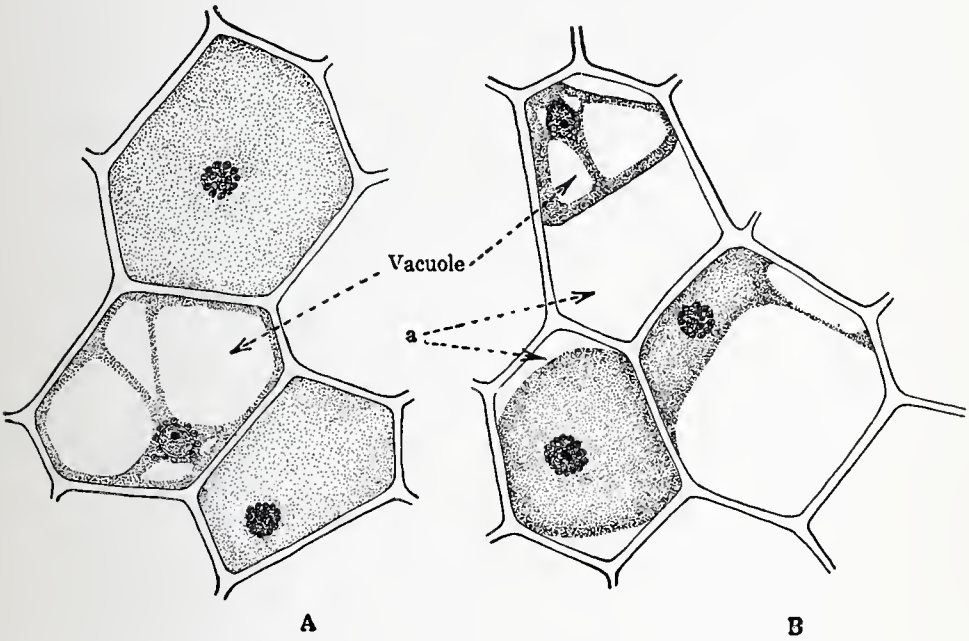

Fig. 7.—Epidermal cells of Wandering Jew. The three cells at the left (*A*) as they appear when immersed in water. The three cells at the right (*B*) as they appear after a brief immersion in 20 per cent solution of cane sugar. Observe that in *B* the living material has shrunken; water has been withdrawn from the vacuoles; the sugar solution fills the space marked *a*. (From Holman and Robbins, in *A Textbook of General Botany*.)

lapse to a certain extent, and in this state, they do not perform their work properly (Fig. 7). Any part of a plant in a wilted condition is incapable of making growth. It may remain alive and be able to recover if given water, but it will not grow. Withholding water from a plant to the extent of causing prolonged wilting cannot fail to retard its growth.

Conditions which Influence the Rate of Absorption.—There are several conditions which have a marked influence upon the rate of water absorption by root hairs. In the first place, when the amount of moisture in the soil reaches a low point, the rate at which it is absorbed by the roots is diminished. There are forces in the soil which hold the water, and unless the forces of absorption exceed these soil forces, water will not be taken in by the roots.

The temperature of the soil is another important factor determining the rate of water intake. The rate is decreased by lowering the temperature, and most plants cease to absorb at or slightly above freezing.

The air supply of the soil also influences the absorption rate. Root hairs do their best work only when they are well supplied with air. In soil that is compacted or so wet that air is excluded from the soil spaces absorption is slowed down.

The strength or concentration of the soil solution is a very important condition determining the rate at which water from the soil enters the plant. Normally, the sap in the root hair is of greater concentration than that in the soil. Under this condition, water moves into the hair through the living membrane which separates the two solutions. If, on the other hand, the soil solution should become more highly concentrated than that in the root hair, water (and only water) would move from the root hair to the soil, and a wilting of the root and entire plant would follow. In an alkali soil, the soil solution surrounding the root hairs is often quite concentrated; at times, the strength may approach that of the root hairs; under these conditions, water movement inward is slow, and the plant finds it difficult to take in as much water from the soil as it loses through the leaves to the air. Water continues to move inward as long as the concentration of the solution inside of the root hair exceeds that of the solution in the soil on the outside. In other words, if the cell sap be denser than the soil solution, that is, poorer in water, water will be absorbed from the soil solution.

It is well known that grass, weeds, and other plants can be killed by drenching the soil in which they are growing with a strong salt solution. It is very probable that in this case the plant

is killed by a failure to absorb sufficient water, rather than poisoned by the chemical. The root hairs, being surrounded by a soil solution which has a greater concentration than that of the root hair sap, die because water is withdrawn from them. Soon, the entire plant dies, for it continues to lose water through its leaves, while at the same time absorption is stopped.

The rate of water absorption is also increased if the rate of water loss from the leaves is increased, providing there is an ample supply of soil water to draw upon.

The movement inward of any particular salt appears to depend upon the available supply in the soil, and the rate at which it is used in the plant. The essential elements which are absorbed by the plant are soon changed into new substances, and so their concentration in the plant is kept constantly less than in the soil solution.

We can understand this behavior better if we consider the following experiment. When slices of potato are placed in water, they remain rigid. All cells are well filled with water, and as a result are swollen. The combined effect is a turgid slice. If, on the other hand, the slices of potato are placed in a strong salt or sugar solution, they soon become limp and flexible; all cells lose water; it is drawn from them into the strong solution outside. As a result, each cell is like a partially deflated automobile tire, and the whole slice is of the same character. It is not altogether the nature of the substance, so much as its concentration, which determines the movement of water in or out of the cell. For example, if the slices of potato are put in a salt or sugar solution the strength (concentration) of which is less than that of the sap in the potato cells, they will remain fresh; instead of losing water they will absorb it. The **cells of the slices will lose water only when the strength of the solution in which they are immersed is greater than that of the solution in them.** Water tends to move from a solution of low concentration to one of higher concentration. As a matter of fact, in most agricultural lands, the soil solution has a lower concentration than has the solutions in the plant. Consequently, the movement of water is from the soil to the plant.

CHAPTER IV

FOOD BUILDING

In the preceding chapter it was pointed out that the plant absorbs from the soil, through its root hairs, water and various mineral salts. The mineral salts are in solution in the water. If a chemical analysis is made of the plant, it will be found that it contains most of the chemical elements which occur in the soil. Even small quantities of some of the rarer elements are absorbed by the plant. However, as pointed out on page 28, students of plant science have found that but a comparatively few of the elements, which the plant takes into itself, actually play an important part in maintaining its life. The indispensable elements absorbed **from the soil** by crop plants are nitrogen, phosphorus, potassium, magnesium, calcium, sulphur, and iron.

In this chapter, we will discuss a most important function of the plant, namely, **food building.** What are the "foods" of crop plants? Out of what materials are the foods made? Where do these materials come from? Where in the plant are the foods manufactured? What is the source of energy for food manufacture? Can plants obtain their carbon from humus in the soil? Are fertilizers plant foods? What use is made by the plant of the various foods? These are a few of the questions to be discussed in this chapter.

Raw Materials and Plant Foods Distinguished.—We are accustomed to speak of the mineral salts containing such essential elements as those given above as the "food" of plants. This statement is not strictly true. A "food" for plant or animal is a substance that can be incorporated **directly** by the living cells and used in making new plant substances. The mineral salts, **as such,** can not nourish the living cells any more than

can nails and tacks, if taken into the human stomach. The mineral salts are used by the plant not as a "food" but as a **raw material from which foods are made.**

The foods—**the substances which are capable of building tissue**—of all plants and animals are identical. The chief foods of plants and animals are substances known chemically as carbohydrates, fats and proteins. Well-known carbohydrates are sugars and starches. Fats occur in the liquid state ("oils") or solid state ("fats"). Proteins are the most complex chemically of all foods. Carbohydrates contain but three chemical elements: carbon, hydrogen, and oxygen; fats also contain the elements carbon, hydrogen, and oxygen but in much different proportion than they occur in carbohydrates; and proteins possess in addition to carbon, hydrogen and oygen, such elements as nitrogen, phosphorus, sulphur, and others.

A Classification of Living Things on a Food Basis.—We have just said that the foods of all plants and animals are the same; they are chiefly carbohydrates, fats and proteins. On a food basis we may divide all living things in the world into two groups: (1) those capable of manufacturing food from the raw materials and (2) those incapable of manufacturing food from the raw materials. In the first group are included all **green plants;** in the second, all animals, and all plants which lack a green color. The first group is independent; the second absolutely dependent upon the first for its food. We, as animals, do not possess organs which enable us to take such raw materials as carbon dioxide, water and mineral salts and make of them carbohydrates, fats and protein. Only green plants have this power; they alone make the food, not only for themselves but for every other living creature.

The Raw Material in Carbohydrate Building (Photosynthesis).—The building of a simple carbohydrate like sugar is the initial process of food building by the plant. **Sugar is the foundation material** upon which the more complex foods, such as fats and proteins, are builded. Without this simple carbohydrate, manufactured in green cells, as a "starter," the more complex foods could not be formed.

Let us now describe the carbohydrate building or manufacturing process peculiar to green plants and to green plants only. The process is commonly known as **photosynthesis,** which means "a bringing together" or building by the aid of light. The raw materials in this process are carbon dioxide and water. Carbon dioxide comes from the atmosphere, water from the soil.

It was for a long time believed that humus (decomposed plant and animal material) in the soil was the source of carbon for plants. But, if a plant is grown in pure sand, free from humus, it will increase in the weight of carbon. Moreover, it has been found by experiment that green plants grown in an atmosphere from which every trace of carbon dioxide has been removed, soon cease to grow, and that green plants cultivated in a soil from which every trace of compounds containing carbon is removed, thrive perfectly. It is concluded that carbon dioxide is essential to a green plant and that the source of carbon in the plant is the carbon dioxide gas of the atmosphere. It is useless to try "feeding" plants carbon by applying fertilizers to the soil. Fertilizers will not furnish the plant carbon. Carbon dioxide enters the plant through small pores in the leaf surfaces; water enters through the root hairs. These two simple chemical compounds or raw materials are brought together in those cells of the plant, chiefly leaf cells, which contain a green coloring matter (chlorophyll). This green coloring matter is not distributed through the cell but is **confined to certain specialized living bodies (chloroplasts).** (Fig. 3, F.) These bodies, containing the green coloring matter, are the real laboratories where carbon dioxide and water are, in some way we do not yet understand, made into food.

The Energy Used.—In any manufacturing process, energy is required. In the food-making process, light is the energy used; it is absorbed by the green coloring materials. The living substances make use of the energy in building a food from the raw materials, carbon dioxide and water. The manufactured product is either a simple sugar or starch. Carbon dioxide, containing the two elements carbon and oxygen, has been united to water, containing hydrogen and oxygen, in such a way as to form a sugar.

It can be easily demonstrated that light is necessary for the manufacture of carbohydrates in leaves. We have learned that sugar is probably the first carbohydrate manufactured; as a rule, some of it is changed to starch, and accumulates during the day in the leaf. The presence of starch may be detected by treating the leaf with iodine, which turns starch grains bluish-purple. A simple experiment consists in covering a portion of a leaf attached to growing plant, which has been in the dark several days, with tin foil to exclude the light. Then, expose the plant to the light for a day. At the end of that period, remove the leaf from the plant, extract the chlorophyll by warming it in alcohol, and then treat the leaf with iodine. That portion of the leaf which was uncovered will color blue, indicating the presence of starch, and that covered, will remain white.

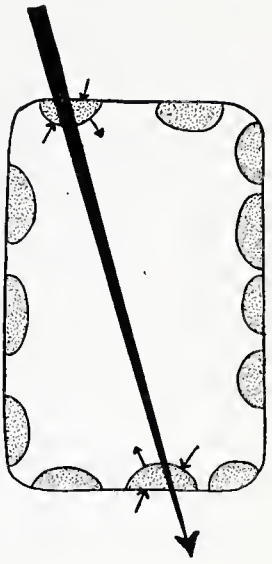

Fig. 8.—Diagram of a carbohydrate-manufacturing cell. The large dark arrow represents a ray of white light penetrating the cell; some of the light passes entirely through the cell, but much of it is absorbed by the chloroplasts, as is indicated in the diagram by the thickness of the arrow. The small arrows represent the interchange of gases between the chloroplasts and the surroundings.

That chlorophyll is necessary for starch manufacture can also be easily demonstrated. Extract the chlorophyll from a variegated leaf of *Coleus*, or other plant which has white areas in it, and treat with iodine. The white areas will show an absence of starch, whereas those which were green will show the presence of starch.

We have seen how there are brought in from the soil such chemical elements as nitrogen, phosphorus, sulphur and others. As stated above, one or more of these are added chemically to the carbohydrate to form proteins. The building of fats and proteins from carbohydrates is independent of light and green coloring material. However, it is

known that in some plants, protein manufacture is particularly active in the leaves.

The carbohydrates, the fats and proteins, are the substances which are capable of being assimilated by the living cells. These tissue-forming substances or **foods** are builded from simple raw materials, carbon dioxide, water and mineral salts.

The Process Summarized.—Thus we see that in the process of carbohydrate manufacture or photosynthesis carried on only by green plants, and only in those tissues of green plants which possess chlorophyll, carbon dioxide and water are the **raw materials**; sunlight the **energy**; special living green bodies chiefly in leaf cells the **factory** or **laboratory**; and sugar the **final product. Carbohydrate manufacture is a process carried on only in cells containing a green coloring matter and only in the presence of light.**

Careful measurements have been made of the amount of light energy which is absorbed by the green leaf, and of the quantity of this actually used in food making. It has been found that about 10 per cent of the total light energy which falls upon the leaf is absorbed by the green coloring matter, and that of this amount only about 35 per cent is used in food making. This means that approximately 3.5 per cent of the energy falling on the leaf is utilized in carbohydrate building.

Use Made of the Carbohydrates.—Part of the carbohydrate manufactured in green tissue is used up in respiration; some of it is converted into cellulose for the formation of the walls of new cells, and for the thickening of old walls of living cells; a portion is used up in the production of oil; part of it is also employed, together with nitrogen, sulphur, and phosphorous compounds of simple character, to form proteins.

CHAPTER V

PRINCIPAL SUBSTANCES TAKEN INTO THE GREEN PLANT, AND THE USES MADE OF THEM

In the preceding chapter it was emphasized that only green plants have the power of manufacturing, from the simple compounds derived from the soil and atmosphere, the foods which are used in building the plant body.

We have also seen that this food manufacturing process is of great significance, in that the foods constructed furnish the material out of which the bodies of **both plants and animals** are builded; and moreover, in the making of these foods by green plants, energy from the sun, which is the world's great and only source of energy, is stored.

It has long been realized by agriculturists that a proper fertilizer practice was dependent upon a knowledge of the influence which the different chemical elements exert upon the plant's growth. If, for example, we would apply nitrates to the soil, we should know how this salt is going to effect the crop. Moreover, we should be able to tell when a crop is suffering from a deficiency of any essential chemical element, and what the effects are of an excess.

Principal Substances Used by Green Plants.—It was also pointed out that there were certain substances which the plant must have in order to maintain life. The principal substances which are taken into the green plant, and in some way made use of, are as follows:

From the soil. (1) **Water,** and (2) **salts** containing principally nitrogen, phosphorus, sulphur, potassium, calcium, magnesium and iron. *From the atmosphere.* (1) **Carbon dioxide** and **oxygen.**

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Let us briefly discuss the part that each of these substances plays in the life of the plant.

Water.—The living material (protoplasm), of the plant is 80 to 90 per cent water. We have learned that water is an essential raw material for the manufacture of sugar. Water is the solvent of the gases, oxygen and carbon dioxide, and also of all mineral salts. None of these substances can enter the plant unless they are in solution. We have seen that raw materials and foods are carried from one part of the plant to another in watery solution. The cells of the plant function normally only when distended with water.

Nitrogen.—Nitrogen is a constituent of all proteins, which are essential components of protoplasm. Protein contains 15 to 19 per cent of nitrogen. It is well known that an abundance of nitrogen tends to produce a rank growth of leaves, stems and roots and to retard the date of maturing of the plant. Crops grown for their leaves only are improved by applications of nitrate. However, an excess of nitrogen in the case of such a crop as cabbage may result in a softness and tenderness which makes it difficult to ship and keep well. Cereal crops produce, as a rule, too much straw, and " lodge " badly if there is an excessive supply of nitrogen. An excess of nitrogen applied to potatoes stimulates a leafy growth, but not a proportionate weight of tuber; applied to tomatoes it produces too much leaf and too little fruit; applied to sugar beets, it results in high tonnage, but reduced sugar per cent. In the case of fruit-bearing plants, heavy applications of nitrogenous fertilizers may cause increased vegetative growth, which is usually associated with decreased fruit production. Nitrates are by far the most efficient source of nitrogen for crop plants.

Phosphorus.—Like nitrogen, phosphorus is a constituent of proteins. It is essential to a rapid multiplication of cells. It is known that such insoluble carbohydrates as starch are not changed into the soluble form (sugar) unless phosphorus is present. In the early stages of the plant's growth phosphorous promotes development. The fact that applications of phosphorus to the soil hasten the maturity of plants is probably due to the stimula-

tion of rapid early growth. On heavy soils, where roots do not form well, phosphorus stimulates root development. Plants secure their phosphorus from the soil phosphates.

Sulphur.—This is an indispensable element in plant growth. It is essential to the formation of proteins. A deficiency of sulphur results in a failure of the cells to divide at a normal rate, and in a suppression of fruit development. The characteristic flavor of onions and garlic is due to certain sulphur compounds. Plants secure sulphur from the sulphates of potassium, calcium, magnesium and iron.

Potassium.—Potassium is essential to the manufacture and movement of carbohydrates. Such plants as sugar beets, potatoes and others which manufacture and store large quantities of carbohydrates are particularly responsive to the available supply of potassium. This element has a marked effect on the weight of grain. Potash starvation shows in the dull, yellowish color of the foliage, in a loss of vigor and a lessened resistance to disease.

Calcium.—This element seems to stimulate root growth. A deficiency retards the movement of carbohydrates in the plant, and their utilization by the plant. Calcium aids in neutralizing acids, both without and within the plant, which might limit the growth. Calcium enters into the composition of the middle membrane of cell walls.

Magnesium.—It is now known that magnesium is necessary for the formation of the green coloring matter (chlorophyll) of plants. In fact, it is a component of the green coloring matter. A deficiency of magnesium results in pale, colorless foliage. Magnesium also appears to aid in the movement of phosphorus in the plant.

Iron.—Although iron does not enter into the composition of chlorophyll, it is absolutely essential to its formation. Even in the light, plants become pale, when grown without iron. Very small amounts of iron salts in the soil are sufficient.

Carbon.—As has been stated, green plants derive all their carbon from the air, in the form of carbon dioxide. Carbon enters into the composition of all carbohydrates, such as sugars, starches, cell walls, and is also an essential component of fats, proteins

and of living material itself. Carbon makes up from 40 to 50 per cent of the dry weight of all plants.

Oxygen.—This element enters into many chemical compounds, but in its elemental form is essential in the process of respiration. This important process will be discussed in Chapter VIII.

It should be understood that the plant is taking in a great many more chemical elements than those mentioned in the preceding paragraphs. The fact is that an analysis of plant ash reveals the presence of most of the elements which occur in the soil. However, it is not known what part, if any, many of the rarer elements play in the plant's life. It may be that some of them, like iron, even in small traces, are indispensable to normal plant growth, or at least influence the plant's development. Experiments seem to bear out the truth of this statement. It should also be pointed out that the salts of the soil are ordinarily in very dilute solutions, and are taken in by the plant in small quantities.

CHAPTER VI

THE MOVEMENT OF SAP IN PLANTS

It is clear that there must be some movement of materials from one part of the plant to another. No one organ or tissue is sufficient unto itself. It is dependent upon certain substances from other organs or tissues. For example, the leaves must have water conducted to them from the soil; and the roots must have foods conducted to them from the leaves. All substances which move from one part of the plant to another must be in solution. This watery substance in the plant is called the "sap." What is the chemical composition of the sap? How does its concentration vary? What tissues of the plant are concerned in the movement of sap? What is the influence of girdling? What is the difference between heartwood and sapwood, as to their conducting power? Why do plants sometimes wilt even though there is an adequate supply of moisture in the soil? These are important questions discussed in this chapter.

Composition of the Sap.—The "sap" of a plant is chiefly water, carrying in solution mineral salts from the soil, and sugars and other soluble foods. The composition of the sap is not the same in all parts of the plant. For example, it may be very different in the bark than in the wood, and in the leaves than in the roots.

Concentration of the Sap.—Nor is the concentration of the sap the same throughout the plant; for example, the concentration of the sap in leaves is usually greater than that of the roots; also the concentration of leaf sap exceeds that of the bark and often that of the green fruit. This difference in the sap concentration between one part of the plant and another is an important factor in causing sap movement. Water tends to move from

tissues of the plant having a low sap concentration to tissues with a high sap concentration. The loss of water by transpiration from the living cells of the leaf maintains in these cells a sap of relatively high concentration, and hence one capable of drawing water from adjacent leaf veins, and these in turn from the stem.

It has been suggested that certain injuries to the tissues of fruits, and the partial wilting or shrinkage of green fruit on very hot days, even resulting sometimes in their dropping, may be due to the withdrawal of water from them by the leaves. This explanation is all the more plausible when we consider the fact that sap concentration in the leaves may become greater than that in the green fruit.

Two Main Sap Streams in the Plant.—Although all living cells of the plant contain sap, not all of them are concerned in its rapid movement throughout the plant. In all stems and roots, there is an **upward-moving sap stream** and a **downward-moving sap stream,** and these differ in their composition. The upward-moving stream is mainly water and mineral salts from the soil; and food substances which have been stored in roots and stems; and the downward-moving stream carries food substances, dissolved, of course, in water.

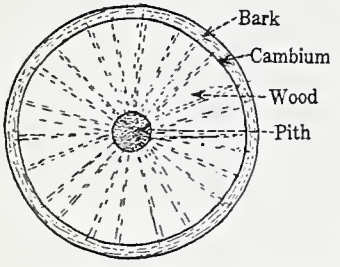

FIG. 9.—Diagram of cross-section of one-year-old woody stem.

Conductive Tissues.—The conductive tissues of the plant are grouped in strands or bundles called vascular strands or bundles (Fig. 1). Each strand or bundle is composed of two groups of structural elements. In woody plants, the bundles are very close together, and form a cylinder of wood and a cylinder of bark (Fig. 9). It is generally agreed that water is carried in the wood, and that foods move downward chiefly in the bark. But there is some difference of opinion as to the tissues in which mineral salts and foods move upwards. According to some workers, mineral salts from the soil, and foods which have been stored in

the roots and stems, are conducted upwards chiefly in the wood; whereas others state that both of these dissolved substances move upwards chiefly in the bark. There is much need for more experimental data before this important question can be settled.

If a section of wood is removed from a twig, and the bark left unbroken, the leaves quickly wilt; but if a ring of bark is

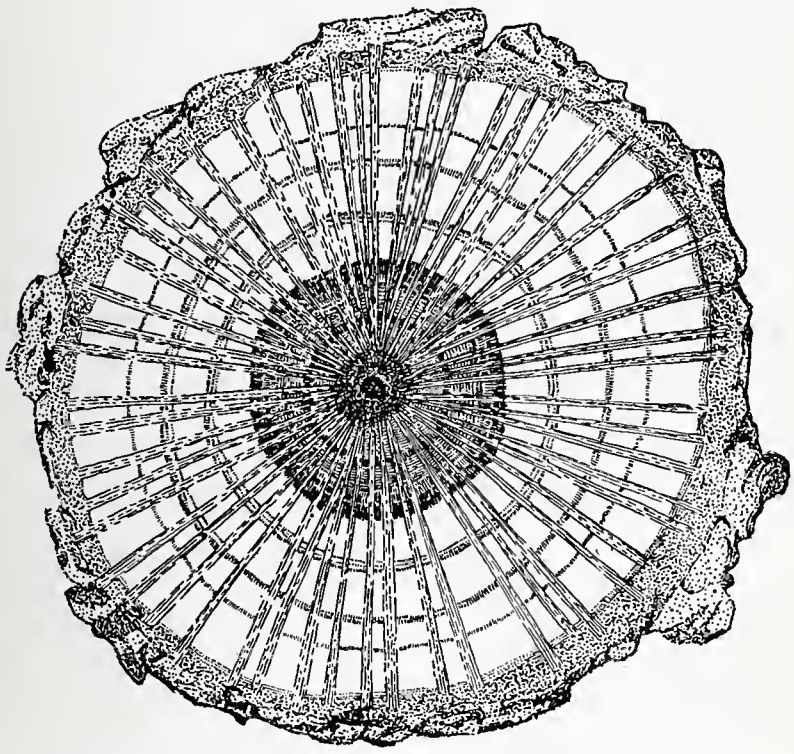

FIG. 10.—Cross-section of six-year-old woody stem. Note the dark-colored heartwood, light-colored sapwood, bark (dotted) and vascular rays.

removed, and the wood left intact, the leaves do not wilt. The movement of water upward in the wood of stems has also been demonstrated by coloring the water in which the lower end of the stem is placed, and observing its path. Although complete girdling of a tree does not shut off the upward movement of water, the downward movement of foods is interfered with, and the tree finally dies. This probably results from the rather

prompt death of the roots, because of their inability to get food. The girdling of stems often results in increased growth above the girdle. This condition also seems to indicate that there is a downward movement of foods in the bark, and that they have a tendency to accumulate above the girdle, thus supplying material for additional growth.

Heartwood and Sapwood.—As a tree increases in age, the conducting elements in the old wood (heartwood), near the heart of the tree, become more or less clogged and sap is no longer able to move through them. It is in the more recently formed wood (sapwood) just beneath the bark, that water moves upward most readily (Fig. 10).

Wilting on Hot, Dry Days.—It is a common observation that on very hot, dry days, plants may wilt slightly even though there is an adequate moisture supply in the soil. It has been suggested that this is due to the inability of the plant to conduct water rapidly enough throughout the body. It is more likely, however, that the absorbing power of the roots is insufficient, or that the absorption of moisture by the root hairs from the soil immediately surrounding them goes on at a faster rate than soil conditions will allow it to be replaced from more remote soil layers.

In any discussion of the movement of sap in plants, the question is raised as to what causes its rise to the tops of such very tall trees as the Australian eucalyptus, which may reach a height of 400 feet. The forces responsible for the ascent of sap have been studied carefully, and many explanations have been advanced, but as yet no completely satisfactory explanation has been offered.

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CHAPTER VII

THE LOSS OF WATER FROM PLANTS (TRANSPIRATION)

THERE is almost no time in the life of the plant that it does not lose water to the atmosphere. In fact **water loss is an ever-present danger.** If for any length of time, the water outgo from the leaves exceeds the water intake by the roots, the plant suffers, and may die. This important water-losing process of plants is known as **transpiration.** All exposed surfaces of the plant are losing water, but **the leaves are the principal transpiring organs.** The water passes off from plants in the form of water vapor.

Transpiration and Evaporation Compared.—In many respects transpiration resembles evaporation, such as takes place from a free water surface. It is different from evaporation, however, in that it is controlled in part by the plant itself. For example, the rate of water loss, by **transpiration,** from a **living plant** is less than the water loss, by evaporation, from a **dead plant.** And, the amount of water lost from a given area of leaf is less than that lost from an equal area of free water surface. For example, it was found in the case of one plant, that a given area of free water surface lost about ten times as much water in an hour as an equal area of leaf surface. As we shall see farther on in this chapter, the living plant has numerous pores on its leaves, which have the power of opening and closing.

The Transpiration Stream.—Although water loss is a constant danger to the plant, the process plays an important role in that it maintains a stream of water (the transpiration stream) from the roots to the leaves, and throughout the entire plant body. There has been a general impression that the greater the rate of transpiration, the greater the rate of intake of mineral

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salts by the root hairs. It has been known by careful experiments, however, that an increase in the rate of transpiration does not proportionately increase the quantity of mineral nutrients absorbed. For example, if by being placed in a dry atmosphere, a plant is caused to absorb and transpire water at double its former rate, the mineral salts absorbed are increased in amount, but are by no means doubled.

The Structure of the Leaf.—Before discussing transpiration further, let us examine the structure of the leaf, an understanding

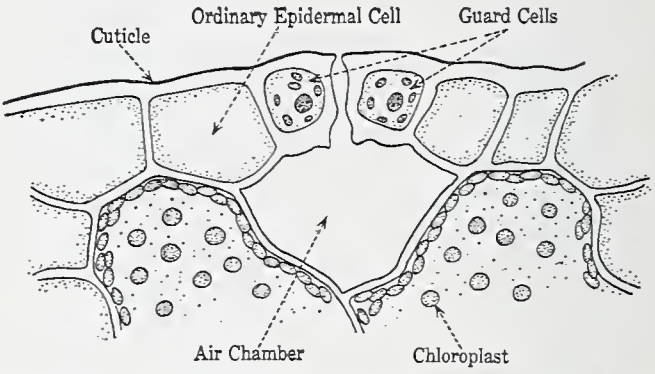

FIG. 11.—A portion of a cross-section of a foliage leaf showing a stomate and a few neighboring cells. (From Holman and Robbins, in *A Textbook of General Botany;* redrawn from Kny.)

of which is necessary to a comprehension of this water-losing process (Fig. 1). Most leaves have a stalk and a broad, flat blade. The surfaces of the blade are covered with an epidermis or skin composed of box-shaped cells, the outer walls of which are thicker than the inner and side walls, and often waxy in nature, such that they effectively prevent the loss of water through them. Here and there in the epidermal layers of the leaves are small openings or pores, known as **stomates.** Each pore or stomate is bordered or guarded by two cells, which differ from all other adjoining epidermal cells, in their shape, in the possession of green coloring matter, and in their behavior (Figs. 11 and 12). In most plants these two " guard cells " of each stomate are capable of changing their shape, and by so doing bringing about the

opening or closing of the pore. We must not understand stomatal closure to mean absolute prevention of water loss; on the other hand, even when the stomates are " closed," there is some water vapor passing out through the small slit.

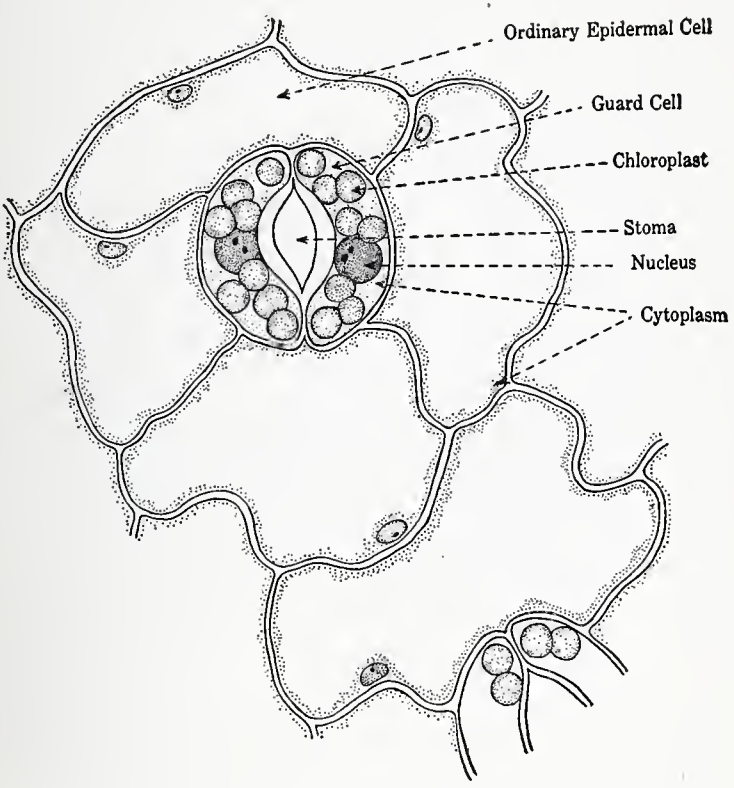

FIG. 12.—View of a small portion of the epidermis from the lower surface of a typical leaf. (From Holman and Robbins, in *A Textbook of General Botany.*)

In this connection, it should be recalled that carbon dioxide gas, an essential raw material in the manufacture of sugar, enters the leaf through the stomates. And, it is probably true that the chief function of the stomates is to admit this gas; or in other words, that it is the need for carbon dioxide which largely controls the opening and closing of the stomates, rather than the need for controlling water loss. For, it is true that in most cases, the

stomates are open when the sun is shining, and conditions favorable for food manufacture, and closed in darkness, when food manufacture is at a standstill. The response of the guard cells of a stomate to wilting is usually slow. In other words, the guard cells are not as efficient in regulating transpiration as we have been wont to believe. But, it should be recognized that in a wilted plant, the stomates are usually in a fairly closed condition, and that the opportunity for water loss is reduced. There are some plants the stomates of which have lost their power of opening and closing.

There are usually more stomates on the under surface of a leaf than on the upper, and in some plants there are none at all on the upper surface. For example, in the apple leaf, there are no stomates on the upper surface, whereas on the under there are approximately 161,000 per square inch; in corn there are about 60,000 per square inch on the upper surface and 102,000 per square inch on the under surface. It has been computed that in a single corn plant of average size there are approximately 104,-057,850 stomates in the epidermis or skin of its leaves.

Between the epidermal layers of the leaf are found the green, food-making cells here and there transversed by veins. The veins conduct water and mineral salts to the green cells, and manufactured foods away from them. The food-making cells fit loosely together, leaving air spaces between them. Moisture is continually escaping from the surfaces of all these cells into the air spaces; and this moisture finds its way to the stomates, and passes out to the atmosphere.

Conditions Influencing the Rate of Water Loss from Leaves.—The rate of water loss from leaves is greatly influenced by external conditions, and it may fluctuate from hour to hour or from day to day depending upon these conditions. Plants lose water much more actively in the light than in darkness. Light may increase transpiration in two ways; by causing the guard cells to open the stomates wide, and by raising the temperature of the leaf. It requires energy to evaporate water, and the more light energy received by the leaf the greater the rate of water loss. It has been determined that as much as 27 per cent of the total

sun's energy received by the leaf is used up in transpiration. Of course, the loss of water to a dry atmosphere is greater than to one of high relative humidity; and it is also known that the rate of transpiration increases with rising temperature, and somewhat with increasing wind velocity.

There are many ways by which plants reduce transpiration. The principal provisions for regulating this process will be discussed in Chapter XV, together with an explanation of the basis of drought resistance in plants.

Wilting and Crispness of Leaves.—It is a common observation that plants become less brittle when they lose water rapidly. For example, lettuce loses its crispness when it wilts. On the other hand, when the tissues are full of water, the leaves are rigid and crisp. In the morning, after a period when water absorption from the soil goes on more rapidly than its loss by transpiration, the tissues of the plant are filled with water, and as a result the stems and leaves are brittle. In this condition they are broken more easily than when partly wilted. In the cultivation of large sugar beets, or other plants where the rows stand close together, and the leaves of one row over-lap those of adjacent rows, it is not advisable to carry on the operation early in the morning because many leaves are broken by the cultivator. Later in the day, when they are less brittle because of a loss of water, the danger of breaking is lessened.

CHAPTER VIII

RESPIRATION IN PLANTS

It is doubtful if it is always fully realized that seeds, fruits, vegetables, and other dormant plant structures must have oxygen in order to maintain life. The losses of fruits and vegetables in storage and in shipment are frequently due to poor ventilation, which usually means an insufficient oxygen supply. It is well to know what the external conditions are which influence the rate of respiration in plant parts, especially in fruits and vegetables, for in respiration the organs actually suffer a loss in the amount of foods stored within them, and also a loss in quality. Refrigeration of perishable fruits and vegetables is done in part with the view of keeping the respiration rate of the living organs at a low level, and thus prevent deterioration in quality.

Respiration Essentially the Same in Animals and Plants.—Respiration is one of the vital processes in plants. In all essential particulars the process is the same in plants and animals. It is true that plants do not have organs in any way resembling lungs, which serve to facilitate the exchange of gases between the atmosphere and the cells of the body, but the essential features of respiration are the same both in plants and animals.

Respiration is a Function of Every Living Cell.—Respiration is a process which goes on only in the living cells. Every cell of the plant body must respire if it is to maintain its life. We have often been led to believe that leaves are the respiring organs of the plant. It is true that respiration is quite rapid in leaves, but they are no more the respiring organs of the plant than are the stems, the roots, and other living parts. Moreover, respiration is not going on any more rapidly in leaves than in many other living organs of the plant. It is in all living cells, no matter

in what organs or tissues they may be found, that respiration takes place.

Respiration a Complex Chemical Process.—Respiration is a process in which substances of the plants, such as sugars, are broken down by the aid of oxygen, into simpler products, the principal ones of which are carbon dioxide and water. It is a destructive process. In this breaking-down process energy is liberated. Some of the energy of respiration is used directly by the living cell for the processes which are essential to its life; the remainder is lost as heat. In respiration, plant foods are used up, being oxidized or burned by means of oxygen. In many respects respiration is similar to combustion. As far as each living cell or the entire plant body is concerned, the exchange of gases involves an **intake** of **oxygen** and an **outgo** of **carbon dioxide.**

Carbohydrate Manufacture (Photosynthesis) and Respiration Compared.—There may be some confusion regarding two processes of the plant, namely, **carbohydrate manufacture (photosynthesis)** and **respiration.** In a preceding chapter the carbohydrate manufacturing process of plants was described. This process, too, goes on in the living cells, but only in those cells which are exposed to light and contain a green coloring matter (chlorophyll). And, in the carbohydrate manufacturing process, carbon dioxide is taken in, and oxygen given off. This is just the reverse of the gas exchange in respiration. Carbohydrate manufacture takes place in a relatively few cells of the plant, and only during the day. Respiration, on the other hand, proceeds day and night in all living cells, whether they contain the green coloring matter or not. Again, we should recognize that whereas respiration is a food-destroying or energy-releasing process, that process peculiar to green cells is a food-building or energy-storing process.

It is very probable that there are times during the day when respiration and carbohydrate manufacture go on at about the same rate in the **green** tissues of the plant. At such times, the oxygen set free in the latter process is not lost to the atmosphere, but is immediately utilized by the cells in respiration, and the carbon dioxide elimated in respiration is taken by the green cells and

used in the process of carbohydrate manufacture. But, during the night when the utilization of carbon dioxide in food building ceases, then this gas escapes from the plant to the atmosphere. In an actively growing green plant, the amount of oxygen liberated to the atmosphere by the carbohydrate-manufacturing process during the twenty-four hours exceeds that absorbed in respiration, and the carbon dioxide contributed to the atmosphere by the respiration of such a plant is much less than that absorbed during carbohydrate manufacture. Thus, we see that green plants play a great part in the scheme of nature, in that they maintain a proper ratio of the important gases of the atmosphere, by removing carbon dioxide from it and adding oxygen. It has been computed that approximately 280 square feet of green leaf surface will give out, during a moderately warm and sunny day, the quantity of oxygen used by a man for respiration during the same period.

Respiration Rate.—The rate of respiration is not the same in all parts of the plant. It is greatest in the rapidly growing tissues, such as occur at stem tips and root tips, in opening flowers and opening leaf buds. Wherever new tissues are being formed, and growth proceeding at a high rate, there respiration is going on at a correspondingly high rate, because of the large amount of work that is being done, and the supply of oxygen needed is great. In the germination of seeds, at which time there is a great activity of the cells, the respiration rate is especially high. This is evident from the fact that a mass of germinating seeds of barley, or other seeds which germinate rapidly, may, if they are prevented from rapid loss of heat, actually become heated until they feel warm to the hand. Again, if fresh green leaves are piled together, the center of the mass soon becomes very warm, since the heat liberated by their respiration can not readily escape.

In resting and dormant structures, such as seeds, bulbs, roots and tubers, the rate of respiration is comparatively slow. But, it must be kept in mind that respiration in such structures **is not entirely suspended.** They contain living cells and they require small amounts of oxygen, and liberate small quantities of carbon

dioxide. If vegetables of any kind are stored in large piles such that there is insufficient movement of air to supply the oxygen necessary for normal respiration of the living cells, and to carry away the products of respiration, there is an actual "smothering" and a deterioration in their quality. Stored seeds, bulbs, roots and tubers must be well ventilated. This means that the living structures, although in a relatively inactive state, actually require some oxygen for respiration.

Factors Influencing the Rate of Respiration.—Various external factors influence the rate of respiration. Among these may be mentioned wounding, which greatly increases the rate temporarily. For example, careful experiments show that injured potato tubers respire fully nine times as rapidly as uninjured tubers. Likewise, wounded or bruised fruits and vegetables of all kinds, which, it must be remembered, are living organisms, respire more rapidly than uninjured ones. When it is recalled that in the process of respiration there is a using up of foods, including sugars, it will be realized that wounded or bruised bodies will actually suffer a much greater loss of sugar than uninjured ones. Temperature is another important factor which influences the respiration rate. The process goes on more rapidly at high temperatures than at low. For example, it has been found that Bartlett pears respire about twice as rapidly at 37° F. as at 30° F.

In the case of potato tubers it has been shown that the respiration rate is greatly increased when they are changed from cold temperatures to higher temperatures, as for example when the tubers are removed from cold storage for transit or for temporary storage at a higher temperature. It is also known that there is a period of high respiration rate in potato tubers immediately after digging. It is recommended that special attention needs be given to the ventilation of potatoes at this time, in order that conditions favorable for the growth of decay organisms will not be created.

Movement of Gases in the Plant.—In animals, oxygen used in respiration, and the carbon dioxide eliminated in this process, are conveyed to and from the cells by the blood corpuscles. In

plants there is nothing corresponding to the blood stream. The sap of a plant does not carry appreciable quantities of these gases. In plants there is, however, an extensive system of air spaces between the cells, which communicate directly with the exterior through the stomates in the leaves, and through loose, open groups of cells (lenticels) in the bark (Fig. 12). Consequently, the cells are surrounded by the gases of the atmosphere, and these can move inward and outward through the moist cell walls. There are certain types of cell walls which will permit oxygen and carbon dioxide to diffuse through them, even when they are dry.

In most crop plants, the system of air spaces in the plant is not extensive and continuous enough to permit ready movement of air through the leaves and stems to the roots. Roots and root hairs absorb oxygen from the air which is present in the soil between the soil particles. In other words, the rapidly growing and active root hairs on a root which is several feet beneath the soil surface obtain oxygen for respiration chiefly from the soil air immediately surrounding them. There is no system of ventilating tubes which is adequate to convey sufficient oxygen from above ground to these subterranean structures except in aquatic and semi-aquatic plants. The normal growth and functioning of the root hairs, consequently the absorption of water and mineral salts from the soil, in fact the health of the entire plant body, depends upon an adequate supply of oxygen to the soil. It is known that the oxygen requirement of roots varies with the temperature of the soil. At a high soil temperature, the amount of oxygen necessary to give a normal rate of growth is greater than at a low soil temperature. Be that as it may, the fact remains that in all our treatments of the soil we should keep in mind the requirement—an ample and constant supply of oxygen in reach of the root hairs. The soil needs ventilation. It must be porous enough to permit the free movement of air through it. If it is crusted on top, due to irrigation or rain, the free movement of air is interfered with, and the roots of plants are likely to suffer from a lack of oxygen. If the soil is extremely wet, the air supply is also diminished. One of the benefits of subsoiling is facilitating the aeration of the soil at lower levels.

CHAPTER IX

THE ROOTS

The vigor of a plant depends to a great extent upon its root development. Differences in root development often account for differences in crop yields. Crop failure is frequently due to an inability of the root system to carry on its work.

In this chapter, there will be discussion of the following questions: Do roots manufacture food? What is the relation between the top growth of a plant and the root growth? How does this relation affect practice when orchard trees are transplanted? What are the principal forms of root systems? What sort of root system makes an effective soil binder? How is the character of the root system influenced by the water content of the soil, its air supply, and the available mineral nutrients? How do cultural practices modify the character of the root system? How is root branching stimulated? What is the depth and extent of the root system of crop plants? Are the root systems of native plants of value in indicating the worth of agricultural lands? How does the character of the root system determine the type of cultivating implement we should use? What is the significance of roots as storage organs?

Interdependence of Root System and Stem System.—It should be kept in mind that the innumerable cells of the root system are devoid of chlorophyll, and hence are incapable of manufacturing their own food. Their food is derived wholly from the leaves, and is carried to them through the stems. Thus, there is an interdependence of the root system and the stem system. The top growth of the plant depends upon the roots for the absorption of water and mineral nutrients, and the conduction of them to the stem; the roots depend upon the top

growth for food. In fact there is a balance between the root system and the stem system. This does not mean that the weight of the root system is equal to that of the top; but the root system must be extensive enough to supply the stems and leaves with sufficient water and mineral nutrients; and the top growth must be adequate to manufacture food for the maintenance of the root system. For example, when a young orchard tree is transplanted, many of the roots of the plant are necessarily destroyed; consequently, the absorbing surface is reduced. The approved practice is to cut back or thin out the stems and thus attempt to reestablish the balance between the two systems. The reduced root system will be unable to supply the tissues of the stems and leaves with sufficient water and salts unless the latter are judiciously pruned. On the other hand, a severely pruned top does not permit of normal growth and development of the roots, for there is insufficient food-manufacturing tissue in the few green leaves which it will bear to supply the relatively larger root system, itself incapable of making food. A condition of unbalance between the root growth and the top growth, if not corrected, will retard the plant's development and may cause its death. It has been shown in the case of fruit trees that when the absorbing area of the root system is reduced by lack of air supply such as will be the case when the water table rises, the trees adjust themselves by shedding some of the leaves and fruits, thus reducing the water-losing surface. The amount of shedding is often proportional to the degree of injury to the roots. It is well known that if the development of the root system of a potted plant is hindered by the size of the pot, the top growth suffers; repotting may become necessary.

Kinds of Root Systems.—There is much variation in the form, the spread, and the depth of the root systems of plants. Three general types of root systems are recognized. The **tap-root system** (Fig. 13) is well illustrated in such plants as the beet, radish, turnip, parsnip, dandelion, maple and pine. In this there is one main root, which grows almost directly downward, giving off numerous branch roots. The **fibrous root system** (Fig. 14) is seen in its typical form in such plants as wheat, oats,

corn and other cereals. In this, one can not distinguish a main root, but there is a great number of relatively small roots of about the same size which form a network. There is still another form of root system, common to many of our fruit trees (Fig. 15), in which there are several large roots of about equal size which

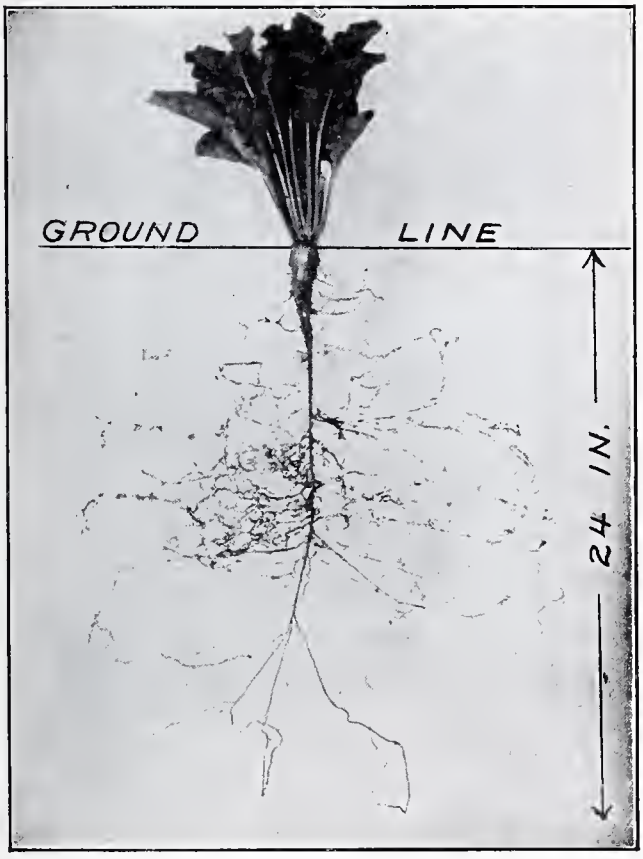

Fig. 13.—Tap-root system of young sugar beet. (From Robbins, in *Botany of Crop Plants.*)

anchor the plant in the ground and which give off numerous finer branch roots.

If soil conditions are favorable, the tap root by its direct downward growth is able to penetrate the deeper layers of soil where more moisture is available; for this reason it is adapted

to dry regions. The tap root of alfalfa, for example, may extend to a depth of 10 or 12 feet, or even more.

The fibrous-root system, on the other hand, is more shallow. Fibrous-rooted plants are employed as soil binders on ditch

Fig. 14.—A sedge, a plant of swampy places, showing the mass of fibrous roots, the above-ground erect stems, and the horizontal stems which grow at or just below the soil surface. The latter serve as vegetative propagating organs.

banks, steep hillsides and in other situations where the soil is likely to be washed away by rain.

Factors which Influence the Growth and Character of the Root System.—The depth and spread of the roots, although

characteristics of the kind of plant, are nevertheless influenced by environmental conditions, chiefly the water content of the soil, the air supply, and the available mineral nutrients. These in turn are modified by tillage, fertilizers, crop rotation, irrigation and drainage.

FIG. 15.—Root system of nine-year-old apricot tree. The roots here have extended to a depth of 18 feet, the elevation of the water table, and have a maximum horizontal spread of 22 feet. (From Division of Irrigation Investigations and Practice, College of Agriculture, University of California.)

The root systems of crop plants in "dry land" and in irrigated soil are usually markedly different.

In most of our fruit plants the root systems extend as deeply in the soil as the air supply of the soil will permit, providing there is sufficient moisture. It is undoubtedly true that air supply of the soil often limits root development. It should be repeated here that all living cells must have a supply of oxygen in order

to live; the root hairs and other active cells of the roots must secure most of their oxygen from the soil air which immediately surrounds them; sufficient oxygen is probably not conducted long distances through the tissues of the plant from above to below ground. The absence or scarcity of root hairs in very wet soil, and in water, is probably to be attributed to poor oxygen supply. In a water-soaked soil, the air spaces are filled with water.

One of the chief reasons usually given for cultivation is that it improves aeration in the lower levels of the soil and thus stimulates root growth at these levels. Orchard trees have been known to die as a result of the " puddling " of the soil. Trees are also sometimes killed by cattle tramping and packing the ground about them, such that the air supply to the roots is largely cut off.

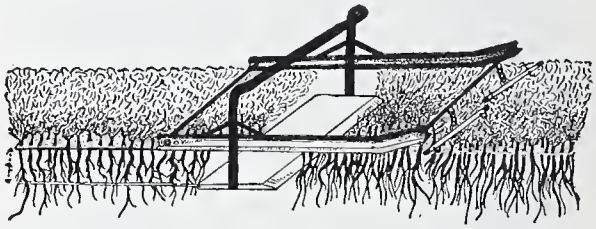

Fig. 16.—Diagrammatic sketch showing method of root pruning redwood seedlings. (From the Redwood Reforester.)

Excessive irrigation may produce an actual decrease in the yield of a crop, chiefly because it produces a soil condition in which aeration is faulty. It has been said that the best irrigation practice involves the most effective compromise between too much water and too little air.

Soil fertility influences the root development of a plant. It has been found that " crops grown in soil of high fertility have roots that are shorter, more branched, and more compact than those in similar but less fertile soil." Moreover, it has been shown that where roots in their growth come in contact with a fertilized layer of soil, they are not only more branched, but they are slow in penetrating the soil below.

Transplanting and root pruning encourage the development of branch roots (Fig. 16). In transplanting, many root tips

are injured and as a result, branch roots are stimulated to develop. Thus, a compact root system is formed.

It has been demonstrated in the case of a number of our crop plants, which were grown in unirrigated, lightly irrigated, and fully irrigated sandy loam soil, that those with the most extensive root systems gave the greatest yield. There is seen to be a close relation between the growth of roots and tops.

The Extent of Root Systems.—The extent of roots is often much greater than that of the top growth. This is true of many native species of plants and also of a number of cultivated plants. For example, in the sugar beet, the main root may extend to a depth of 5, 6 or 7 feet, and give rise to numerous branches which spread laterally several feet. Corn has a root system which may occupy as much as 200 cubic feet of soil. Weaver points out that a corn plant in the eight-leaf stage has from 8000 to 10,000 lateral roots from the 15 to 23 main roots. A five-weeks'-old corn plant grown in a fertile, moist soil developed a root system the absorbing area of which (excluding the root hairs) was 1.2 times as great as the area of the top, and in a dry soil 2.2 as great as the area of the top. Weaver also found that the root area of Turkey Red winter wheat exceeded that of the top by 10 to 35 per cent. The roots of common asparagus may extend to a depth of 8 or 9 feet and as far laterally, occupying the soil very completely. The roots of a seven-year-old apple tree were known to spread horizontally more than 12 feet and to a depth of 9 feet.

Native Plants as Indicators of Agricultural Lands.—Weaver studied the root systems of cereals in the principal types of grassland which constitute such a large part of the Mississippi Basin. This was done to determine for one thing if native vegetation is of value in indicating the worth of agricultural land. These grassland types are characterized as follows: (1) The **true prairie** has a luxuriant growth of numerous species of tall, sod-forming grasses. As compared with the (2) **short-grass plains,** the prairie has greater precipitation, less run-off of rainfall, and a lower rate of evaporation. The **short-grass plains** is characterized by a sparse growth of a few sod-forming short-

grasses. Between the short-grass plains and the true prairies, there is a distinct belt of vegetation, in central Nebraska and Kansas, known as the (3) **mixed-prairie,** which contains one or more of the short grasses, growing beneath the taller prairie species. Weaver found that the root growth of cereal crops was greatest in the true prairie, least in the short-grass plains, and intermediate in the mixed-prairie. The same relation was found to exist between the majority of the native species of these three types of grassland. In other words, there is a striking similarity between the development of the roots of crop plants and that of the native vegetation growing in the same environment. Thus it is seen that different environmental conditions greatly affect root development; furthermore, it is believed that natural vegetation has considerable value as indicating lands of agricultural or non-agricultural worth.

Root Systems and Cultivating Machinery.—The development of cultivating machinery has been directed in a large measure by a knowledge of the root systems of cultivated plants. For example, there are special types of cultivators for corn, which are so constructed as to do no harm to the shallow lateral roots of this crop. The first cultivation of sugar beets can be with implements which run close to the row, for the young tap root at this time has very few laterals; but after the first cultivation, attachments to the cultivator are omitted which may disturb the soil close to the rows. By this time the rootlets are rapidly growing and spreading in the soil, and in close cultivation there is danger of destroying them. So it is seen that a knowledge of the root systems of plants at their various stages of growth is a guide as to the best types of implements and the best methods to use in stimulating their normal development.

Roots as Storage Organs.—The roots of many plants act as storage organs. The stored products may be foods and water. Familiar examples of roots which become large and fleshy as a result of the food stored in them are the parsnip, carrot, radish, turnip, rutabaga, dahlia, sweet potato and beet. The principal storage product of the sugar beet root is sugar, whereas that of most other roots is chiefly starch.

The roots of perennial plants store large quantities of foods, even though they are not greatly enlarged and fleshy. For example, in the fruit trees, both large and small roots are very rich in storage material. The roots of alfalfa and red clover are filled with starch. In asparagus there is a tremendous mass of rather fleshy roots which serve as storage organs (Fig. 17). In

Fig. 17.—Root system of asparagus partly exposed. Note the mass of fleshy storage roots and edible "spears.

this plant, the new edible shoots sent forth in the spring are made wholly at the expense of food stored in the roots, and it should be emphasized that the quantity of this food depends upon the amount and vigor of the top growth made by the plant during the season prior to the cutting of the spears. The persistence of some weeds, such as the dandelion, is due to the large amounts of food stored in the roots, and also to the ability of the roots to produce new top growth when cut into pieces.

CHAPTER X

STEMS AND PRUNING

In order that we may better understand grafting, and the propagation of plants by the use of stems, and some of the principles of pruning, it will be necessary to know a few of the characters of stems and their manner of growth.

How do stems grow in length? How do stems grow in diameter? What is the difference between "summer wood" and "autumn wood"? Is it possible to graft stems that have no cambium (growing) zone? What are the purposes of pruning? Why do some trees tend to fruitfulness, whereas others "go to wood and leaves"? Does pruning have an influence upon the fruitfulness or vegetativeness of a tree? How should branches be cut from a tree in order that the wound will heal properly? These are some of the questions that will be discussed in this chapter.

External Characters of Stems.[1]—If we examine a **leafy twig** of some woody plant, the cottonwood, for example, we observe that it is divided into sections (**internodes**). At the enlarged joints (**nodes**), the leaves arise. Buds develop in the axils of the leaves, and also at the tip of the branch. In most of our common orchard and other trees, the buds that develop on the stem may be first observed in late summer or early fall. By winter time when the leaves are off, the buds have attained full size.

If we examine a twig (Fig. 18) in the winter when the leaves are off we see at the tip a large **terminal bud**. If it is broken open, young overlapping leaves are found within. It develops the following spring into a branch which, in turn, bears leaves. Along the side of the stem are **lateral buds** at regular intervals. These may be leaf buds or flower buds, as can be positively determined by breaking them open. Below each bud there is a half-

[1] The account on pages 52 to 59 is taken with but slight alterations from Robbins' *Botany of Crop Plants*, published by P. Blakiston's Sons and Co., Philadelphia, Pa.

moon-shaped **scar.** The leaf was attached at this point, and when it fell, a scar was left. By examining the leaf scar with a hand lens one sees several small **bundle scars** on the surface. These scars are left by the conducting strands that pass from the woody stem into the stalk of the leaf. The large circular or oval scars on a twig are left by the falling off of fruits or fruit clusters.

The length of twig growth made each year is clearly distinguished by a ring of scars. When the closely arranged bud scales of a terminal bud fall off in the spring they leave a number of scars so close together as to make a **ring.** Hence, the limits of two successive years' growth are marked by the scale scars of terminal buds. The age of a twig may be determined by counting these rings of scars.

Close observation of the twig will reveal a number of whitish spots on the bark. These are **lenticels,** structures on the stem composed of a mass of loosely fitting cells which permit the move-

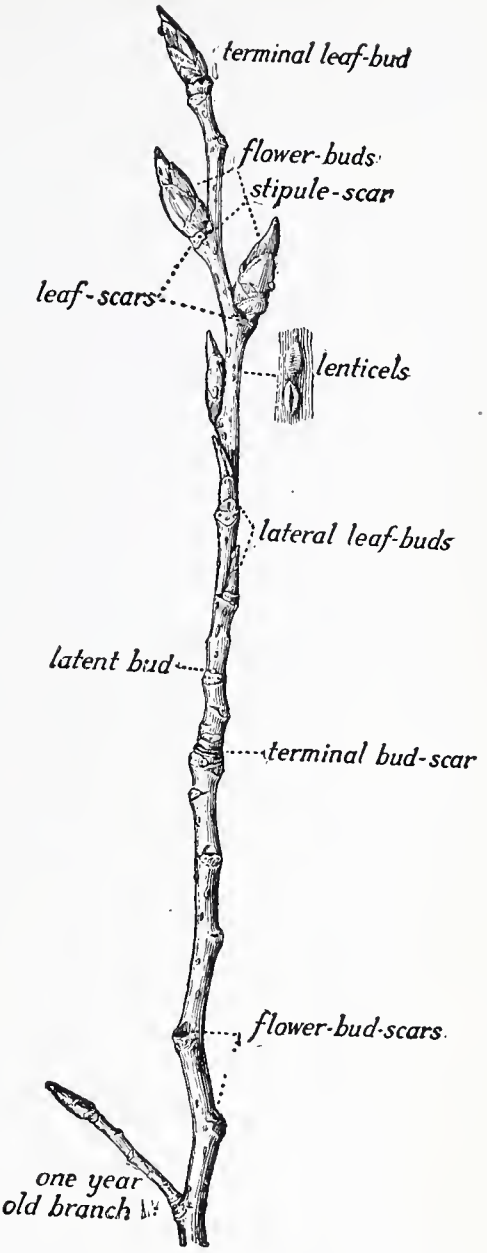

FIG. 18.—Cottonwood twig two years old. (From Robbins, in *Botany of Crop Plants.* Drawing by Longyear.)

ment of gases inward and outward. Except for the lenticels, the bark prevents the free passage of air, and also the loss of water from underlying stem tissues.

Buds.—A bud is an undeveloped stem; it is simply a young shoot. It may be a leafy shoot or a flower shoot, or bear both leaves and flowers. In an ordinary shoot, an apple or peach twig for example, the internodes are long. In rapidly growing water sprouts, internodes may be several inches in length. A bud is a very short, young shoot in which the internodes are few or are exceedingly short. That a bud is a young, individual shoot in itself is shown by the fact that buds may be removed from a branch and applied to the surface of the growing tissue (cambium) of another branch (stock) and successfully grown there. In fact, bud grafting (budding) is a common horticultural practice. The tip of the bud is usually protected by a series of overlapping scales (bud scales). Naked buds are not protected by scales; they are found on woody plants of the moist tropics, and are the only sort on herbaceous plants the world over.

Kinds of Buds.—Buds may be classified as to development into: (a) **leaf** or **wood,** (b) **flower,** or **fruit,** and (c) **mixed buds.** If we open up a **leaf,** or **wood bud,** we find a very much shortened axis or stem bearing a number of small leaves. As the leaf or wood bud is a young shoot, it may just as properly be called a **branch bud;** that is, it lengthens into a branch which bears leaves. The new shoot, just as the old one from which it came, ends in a bud and in the leaf axils other buds arise. If we open up a **flower** or **fruit bud,** we find one or more young flowers. In plums, for example, the number of flowers in a bud varies from one to five, two and three being the most common numbers. **Mixed buds** contain both flowers and leaves. The terminal buds at the ends of the short "spurs" in the apple are mixed buds (Fig. 19).

It is not always possible to distinguish leaf from flower buds by their external appearance. In some cases, however, they have a different shape. In the apple, for example, fruit buds (here, really mixed buds) are rather thick and rounded, while leaf buds are smaller and more pointed. In all plums, the flower buds are

lateral, and usually stand out at an angle of about 30°, while leaf buds are more appressed to the stem.

Buds may be classified as to their **position on the stem** into:

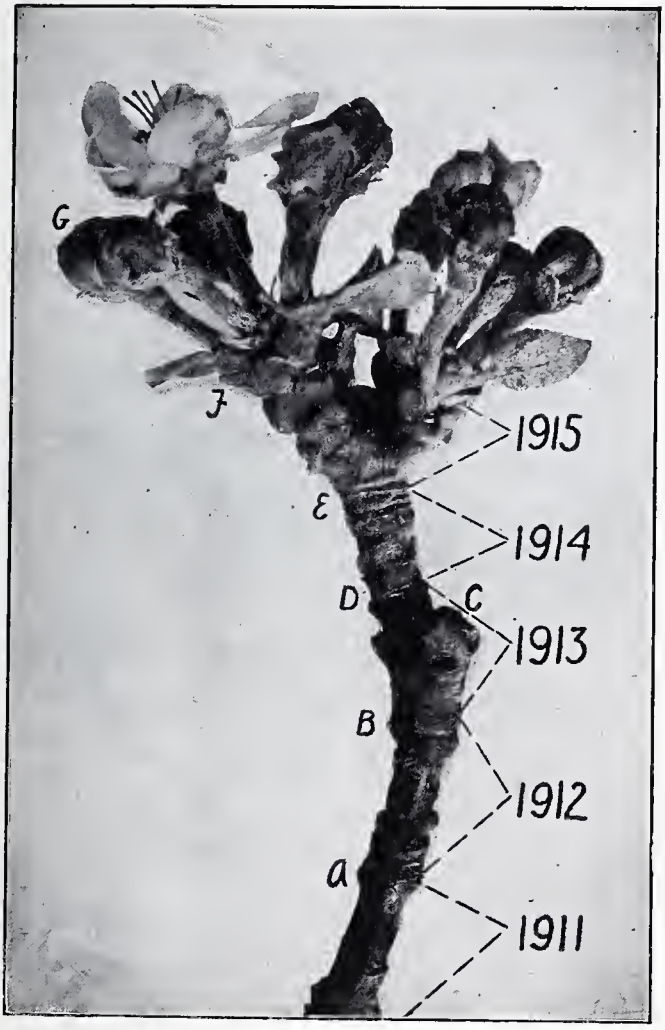

FIG. 19.—Fruit spur of yellow Transparent apple. (From Robbins, in *Botany of Crop Plants.*)

(a) **terminal,** (b) **lateral** or **axillary,** (c) **accessory,** (d) **adventitious,** and (e) **dormant.**

Most stems end in a bud. Such a **terminal bud** is almost

always a leaf bud; occasionally it bears flowers, too, as in the apple and walnut. The terminal bud is normally the most vigorous of all on the stem, as is evidenced by the fact that it elongates into a shoot which exceeds in length those from the lateral buds. **Lateral** (side) **buds** arise in the leaf axils. They give rise to side branches or to flowers. Fruit buds are often lateral on the stem. For example, on long shoots of the past season, almost all the fruit buds of the peach, quince, olive, currants and gooseberries are lateral; and a number of those of apricots, almonds, plums and cherries have a lateral position. On " short-lived spurs," most of the fruit buds of apricots and almonds, are lateral; and on " long-lived spurs," most fruit buds of sweet cherries and a part of those of sour cherries occur in this position.

Accessory buds are extra ones coming out in the leaf axils. They are best shown in the maples, and box elder, and walnut. **Adventitious buds** arise out of order, in unusual places, not in leaf axils or at the end of a stem. They are usually stimulated by injury. For example, when a branch is cut back, numerous adventitious buds develop near the edge of the cut surface. **Dormant buds** are ones that have arisen in a regular fashion in the leaf axil, but which, for some reason, do not develop. Such buds lengthen somewhat every year so that the growing point is at the surface of the bark. They may be called into activity later in the life of the plant.

How Stems Grow in Length.—As has been stated, a bud is a young shoot. A lengthwise section of a stem (leaf) bud shows a cone-shaped growing point upon which is a number of young leaves. These leaves come off at regular intervals, following identically the same arrangement as they do in the adult twig. The growing point, then, consists of a number of very much shortened internodes. Growth in length of the shoot consists in the lengthening of these internodes by increase in the number and the size of cells that compose internode tissue.

It appears that in many plants the number of leaves that will be on a twig is already fixed in the bud, and that new leaves do not originate during the growing season. However, in other cases, new leaves do form during the growing season. Another

point worthy of special mention is that when a twig has made its year's growth, the internodes do not lengthen during subsequent years. Increase in length of that shoot is due to the addition of other "joints" at the end. The fixed length of old internodes is well proven by the common observation that nails driven into the trunk of a tree, or a branch, are not elevated above the ground as the tree grows. It will become grown over with wood, but its height above the ground remains the same. A common impres-

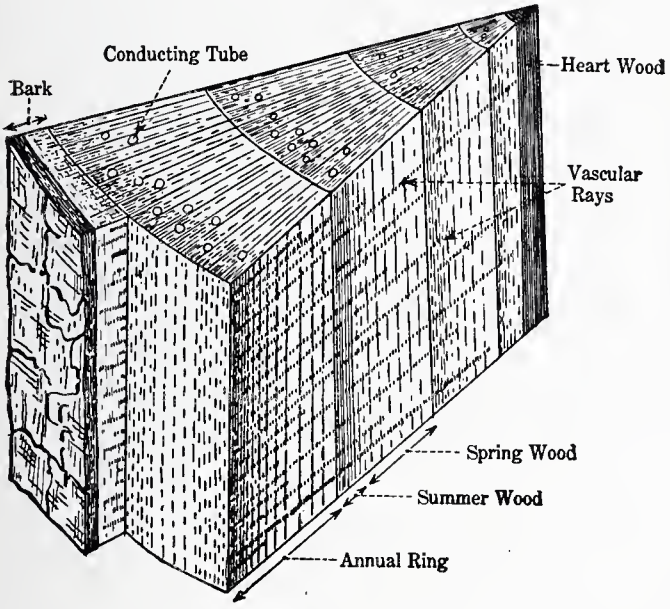

FIG. 20.—Portion of a four-year-old stem of the pine, shown in transverse, radial and tangential views. (Redrawn from Strasburger.)

sion prevails that, in pruning, the branches of a young tree should be started low to the ground, so that they will be at about the proper elevation above the ground when the tree reaches maturity. The erroneous supposition here is that the limbs are raised by the growth of the tree.

Structure of Stems.—A cross-section of a woody stem, such as a twig of the cottonwood, cherry, or apple, shows three distinct regions: the **bark,** the **wood,** and the **pith** (Figs. 9 and 20). The bark may be peeled away from the wood. It separates

from the wood along a region known as the **cambium.** The slimy surface of the wood from which bark has just been removed is due to the protoplasm from the broken cambium cells.

The **cambium** is composed of thin-walled, tender cells, capable of rapid division and growth. **The cambium is in fact the growing layer of the stem.** In grafting, one stem, the **scion,** is inserted into or attached to another stem, the **stock,** in such a way as to bring the two cambium layers together. After a time the cells of these layers grow together.

The **bark** is covered with a corky layer which successfully prevents the rapid loss of water from the stem. Beneath the corky layer of the bark are several layers of cells containing chlorophyll, and hence capable of manufacturing sugar. The inner part of the bark is the **phloem.** The phloem is that portion of the stem which is largely concerned in the conduction **downward** of foods manufactured in the leaves (probably mineral substances and foods **upward,** also). Large tubes, known as **sieve tubes,** in the phloem are the conducting elements. In addition to cork, chlorophyll-bearing tissue, and phloem or food-conducting tissue, the bark may have fibers and other cells which give strength.

The **wood** of the stem is made up chiefly of large conducting tubes (**tracheal tubes**), fibers, and storage cells. It is in the tracheal tubes that water (and probably salts and foods, also) is carried. The fibers give strength to the stem. The storage cells store water and foods, and may also conduct these substances short distances.

The **pith** of the stem consists of a group of large, thin-walled cells which store food to some extent. The amount of pith in stems varies greatly.

Radiating from the pith, and extending through the wood and the phloem part of the bark, are rows of cells which constitute the **vascular rays.** Water, salts and foods are carried radially in these ray cells; they also serve as places of food storage. If a cross-section of a twig is treated with iodine, starch, which is stained blue, is seen to occur chiefly in the vascular rays and in the outer cells of the pith.

How Stems Grow in Diameter.—In stems of the type to which our common orchard trees belong, there is a continuous **cambium layer** between the bark and the wood. The cambium cells divide and redivide, adding to the bark cells on the outside, and to the wood cells on the inside. Hence, by a division of cambium cells, new phloem is laid down on the **inside** of old phloem, and new wood is laid down on the **outside** of old wood. A layer of phloem and a layer of wood are formed each year. The phloem rings are less distinct than those of the wood and as the stem grows older the older phloem may peel off with other bark tissue.

Annual Rings.—An annual ring, as generally understood, is one year's growth of wood. The ring varies in width, depending upon the time in the life of the plant it was formed, and upon seasonal and climatic conditions. Furthermore, it is known that some trees grow rapidly, producing wide annual rings, while it is a specific character of others to grow slowly, i.e., produce narrow annual rings. The amount of carbohydrates supplied by the leaves and the water supply are two chief factors determining the width of rings.

There is usually a marked difference in the wood formed in the spring and early summer, and that produced in late summer and fall (Fig. 20). In early or so-called "**spring-wood,**" conducting tubes are large and quite numerous; in late or "**summer-wood,**" conducting tubes are smaller and fewer, and wood fibers are relatively more abundant. Hence, "summer-wood" has more strength than "spring-wood." The summer wood of one year (say 1925) is adjacent to the spring wood of the following year (1926).

"**Soft wood**" is usually one which grows rapidly. The conducting tubes are rather small and uniform in size and evenly distributed throughout the year's growth. "**Hard wood**" is usually a comparatively slow-growing wood. The conducting tubes of the spring and early summer are large and numerous, while the autumn wood is solid as a consequence of the greater abundance of strengthening elements.

Stems of Monocotyledons.—The name "**monocotyledons**" refers to a group of flowering plants which have but one seed leaf,

Moreover, the flowers usually have the parts in groups of three, that is, three sepals, three petals, two groups of stamens of three each, and the ovary with three seed cavities. The stems of monocotyledons differ in structure from those of dicotyledons which have been described above. Familiar examples of monocotyledonous plants are cereals and other grasses, onion, asparagus, lily, iris and orchid.

The corn stalk is an excellent example of a monocotyledonous stem. In this the vascular strands (bundles of wood and phloem) are scattered (Fig. 21). They do not form a definite " vascular

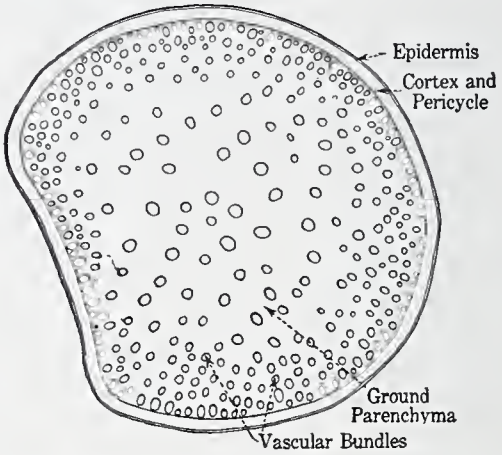

Fig. 21.—Diagram of a cross-section of the corn stem. Note the scattered vascular bundles characteristic of the monocot type of stem. (From Holman and Robbins, in *A Textbook of General Botany.*)

ring " as in dicotyledonous stems. Moreover, the vascular bundles of most monocotyledons do not possess cambium. Hence, new phloem and wood are not produced each season, and there are no annual rings formed. Growth of monocotyledon stems results chiefly from simple enlargement of cells derived from the growing tip. Since such stems have no cambium layer, it is impossible to graft them.

Pruning Defined.—Pruning is a practice in which some portion of the plant is removed in order that the part which is left will better serve the purpose of man. The parts of the plant

removed may be roots, or branches, or buds, or flowers, or fruits. The most common kind of pruning is that which involves the removal of branches.

The pruning of fruit trees is done with the object of (1) giving the plant a desired shape, and (2) changing its behavior, chiefly its fruitfulness. Of course it is practically impossible to change the shape of a tree without at the same time modifying its behavior. We sometimes refer to the practice of changing the shape of a tree

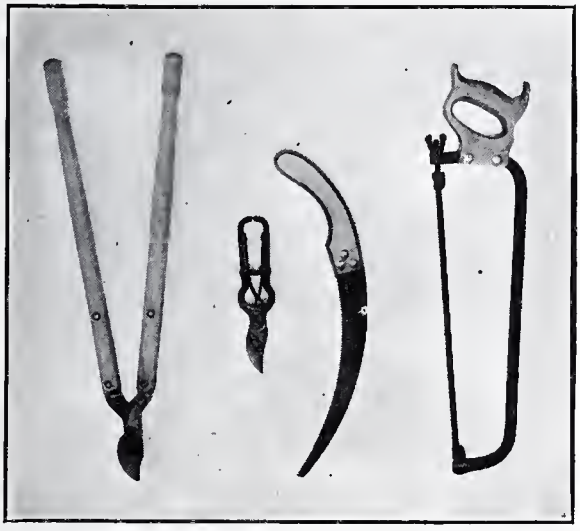

FIG. 22.—Pruning tools. (From Division of Pomology, College of Agriculture, University of California.)

as "training"; it is of great importance during the early life of the plant.

The Effect of Pruning.—It should be especially emphasized that the principal effect of pruning is a modification of the nutritional balance in the plant. The immediate visible effect of pruning is to stimulate growth close to the cut portion of a few vigorous shoots. This response may be due in part to an increase in the water and nitrogen supply to those portions remaining, for the total numbers of growing points has been reduced whereas the absorbing surface has not been diminished. The net result

of any kind of pruning on young non-bearing trees is to retard the development of the entire plant—tops and roots.

The Purpose of Pruning.—We may state the purposes of pruning as follows:

1. To establish a mechanically strong framework, which will enable the tree to bear the load of heavy crops, and of the strains occasioned by high winds or heavy snows. Trees properly trained when young will not need the bracing and propping that untrained trees need.

2. In the case of ornamental trees, to develop a symmetrical plant with beauty of form.

3. To secure a tree of such size and shape that a minimum of labor will be required in harvesting fruit from it, and that the costs of spraying and fumigation will not be prohibitive.

4. To bring about an even distribution of the fruit over the entire tree. Unpruned trees may become so dense that sunlight does not reach the interior branches, and consequently, fruit production is limited to the outer parts of the tree.

5. To regulate the size and quality of the product.

6. To maintain profitable production over a series of years.

7. To remove dead or dying parts which may endanger the life of the plant.

Vegetative and Reproductive Activities of the Plant.—It was stated that the chief effect of pruning is a disturbance of the nutritional balance of the plant. Let us discuss this point more fully.

The parts of the plant body may be classified according to the work they do, into two groups: (1) those that carry on **vegetative activity,** and (2) those that carry on **reproductive activity.** In our ordinary crop plants, the stems, leaves and roots are chiefly concerned with maintaining the life of the individual plant, that is, carrying on the vegetative functions such as absorption of materials from the soil, manufacture of foods, respiration, transpiration, etc., while the flowers which produce seeds, carry on the reproductive activities, and thus preserve the life of the race.

It is a common observation of those who have grown plants, that the production of leaves, stems and roots, that is, **vegetative**

growth, is stimulated and promoted by environmental conditions which are somewhat different from those best suited to the production of flowers and seed, that is, **reproduction.** In a measure, vegetative activity and reproductive activity are opposed to each other.

Conditions which tend to check vegetative growth favor fruit production. In the case of beets and celery, the tendency for the plants to send up seed stalks prematurely, appears to be associated with conditions which retard vegetative extension of the plant. The flowering and seeding of certain annuals may be postponed for a long period by placing them in the greenhouse under very favorable conditions for growth. It is a common observation that plants which develop an abundance of vegetative growth set fruit but sparsely; a very severe winter pruning which stimulates vigorous growth of shoots usually results in a small production of fruit.

We have often been prone to " explain " the complex relation which exists between vegetativeness and reproductiveness, by saying that when in the life of the plant conditions arise which threaten its extermination, it is thereby stimulated to produce reproductive organs. This is a statement, not an explanation. Let us look further.

We should have fresh in our minds at this point some of the facts concerning the nutrient relations of the plant. We know that carbohydrates are manufactured only in the presence of light and in green cells, chiefly those of the leaves. Carbohydrates are made from carbon dioxide and water. Carbon dioxide comes from the air; water is derived from the soil. Carbohydrates are the main sources of energy for plant growth; and they form the the basis upon which the more complex foods are builded. When plant proteins are formed in the plant, nitrogen chiefly, and other elements, are added to the carbon, hydrogen and oxygen of the carbohydrate. The nitrogen is derived from nitrates which enter the roots from the soil. We may picture, then, the coming together of carbohydrates and nitrates in certain living cells. As the result of chemical changes, not well understood, simple organic nitrogenous compounds are manufactured from them.

Now, it must be evident that with a given quantity of carbohydrates in the cells, there is a definite amount of nitrogen which can be utilized. Or to state the matter in another way, in the manufacture of a quantity of nitrogenous foods, there will be utilized a certain amount of carbohydrates and a certain amount of nitrates. If the carbohydrate manufacturing process proceeds at a greater rate than nitrogen, absorbed from the soil in the form of nitrates, is utilized, then there will be, of course, an accumulation or surplus of carbohydrates. It has been shown experimentally that when there is a surplus of carbohydrates in the plant, but at the same time no deficiency of nitrogen, conditions are right for maximum fruitfulness. If, on the other hand, the supply of nitrogen and carbohydrate is ample, but there is no carbohydrate surplus, then vegetative growth is favored, and little or no fruit is produced. In the event there is nitrogen starvation, even though carbohydrates are ample, or in the event there is carbohydrate starvation, even though nitrogen is ample, both vegetative activity and reproductive activity are retarded. Thus it appears that the supply of nitrates and of carbohydrates is important in determining the degree to which a plant will be vegetative or reproductive. It should be mentioned at this point that a scarcity of water limits growth, not only on its own account, but because it is a solvent of nitrates and other mineral salts. Nitrates even though abundant in the soil are unavailable unless there is ample water to dissolve them and carry them into the plant. If there is a lack of water, even though there is a supply of both nitrates and carbohydrates, the plant will tend to fruitfulness.

Whether or not a fruit tree will tend to wood production (vegetativeness) or fruit production (reproductiveness) depends upon the environment affecting the forming buds. High nitrogen supply in the soil resulting in a flow of raw materials to the forming buds, if coupled with a carbohydrate supply from the leaves, will induce the development of a large supply of **wood-forming** buds; whereas a moderate flow of nitrates to the forming buds, coupled with an accumulation of carbohydrates will induce the development of **fruit-forming** buds.

Now, it must not be thought that a very vigorous vegetative growth excludes the possibility of the plant being fruitful. In order that flowering may be initiated, there must merely be more carbohydrates manufactured than can be utilized for vegetative growth.

Summarizing we may say that the conditions favoring continued vegetative growth are: (a) An abundance of available

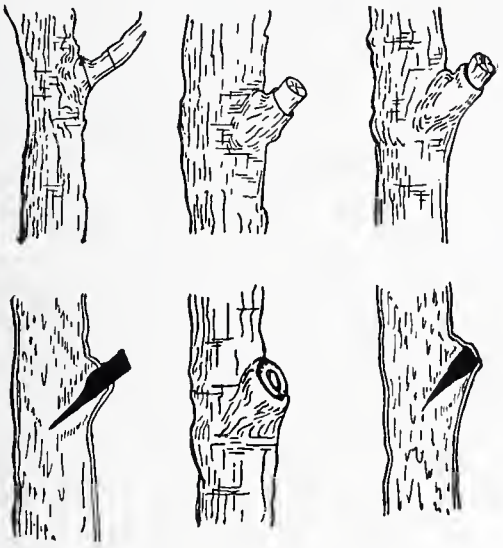

FIG. 23.—Improper removal of a limb may result in decay that is carried far into the tree. In the above, a stub was left, which does not heal over; the stub finally decays, and falls out. The dark-colored portion represents decayed tissue. (Redrawn from Solotaroff in *Shade Trees in Towns and Cities.*)

mineral nutrients in the soil, particularly nitrates, coupled with an available carbohydrate supply; (b) optimum temperature conditions; (c) and an ample supply of water. And, the conditions which induce reproductivity are: (a) A balance of carbohydrate manufacture over its utilization; (b) temperatures which depart from the optimum; (c) a limited water supply.

We may rightly ask now what the foregoing discussion has to do with pruning practice. Whenever branches are cut from a tree, there is removed a quantity of stored food, the carbo-

hydrate-manufacturing surface of the tree is reduced, and the balance between the nitrogen absorbing area and carbohydrate manufacturing area is destroyed. Young trees are normally vegetative; with their relatively small leaf area, there is no accumulation of carbohydrate reserves. If the tree is pruned heavily during its early life, such that the food manufacturing surface is kept low, the period of fruit bearing is postponed. In the first place the size of the tree is greatly reduced, and secondly, the nutritional balance is disturbed.

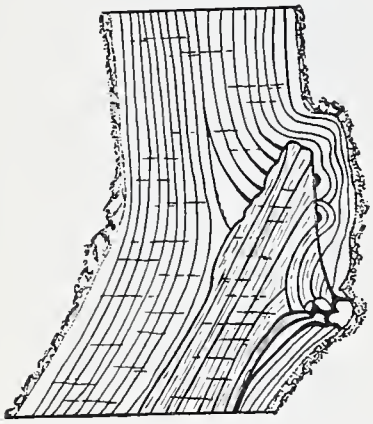

Fig. 24.—A side branch which was cut off has been grown over. The darker, central portion is the cut end of the branch. (Redrawn from Sorauer.)

If we should apply nitrogen to the soil, and at the same time prune heavily, the result would be a greater degree of vegetativeness than if one pruned heavily but did not apply nitrogen.

If there were an actual deficiency of carbohydrates, even though nitrogen were abundant, the tree would be weak and unfruitful. This carbohydrate deficiency may be brought about by defoliation as the result of insect or fungous attacks. And, too, as is frequently the case in old orchards, if there is an abundance of carbohydrates stored in the twigs, but a lack of nitrogen in the soil, the tree will also be weak vegetatively and non-fruitful. In this event, both vegetative growth and fruitfulness may be restored either by application of nitrogen to the soil, or by pruning the top. Of course, in the above case, the best practice would be the application of nitrogen fertilizers together with judicious pruning.

Although pruning is one of the principal means of regulating the carbohydrate supply and the nitrogen supply of the tree, it is not the only one. Cultural practices which control the available water in the soil, and fertilizers, are fully as important.

The Healing of Wounds.—When a stem is removed in pruning, it should be cut close to the trunk or branch from which it arises. Fig. 23 shows proper and improper methods of removing a branch. If a leafless stub is left, the tissue at the end of the stub receives insufficient nourishment to enable it to heal over readily; consequently, it becomes rotted, the decay traveling down into the larger branches or trunk. The cut should be close to the branch or trunk from which the pruned part is taken, so that the cambium of the branch or trunk may heal the wound.

CHAPTER XI

THE FLOWER, POLLINATION AND FERTILIZATION

Why is there often a failure of blossoms to set fruit? How can one carry on artificial pollination and the crossing of plants? What is the cause of misshapen fruits? What is the difference between self-fertilization and cross-fertilization? How long will pollen remain viable? How is pollen carried? What is the cause of seedless fruits? What is the structure of flowers, particularly those of our most common crop plants? These are questions the answers to which the agriculturist will wish to know. They are discussed in this chapter.

In the higher plants, including cultivated plants of all kinds, the flower is the organ of sexual reproduction. It is in the flower that the seed is developed.

Many plants can be multiplied by means of vegetative organs, such as stems, roots, and sometimes leaves, but the principal way in which they multiply is by means of seeds, which are a product of the flower.

Parts of the Flower.—In most flowers there are four principal parts, which, taken in order from the outside to the inside of the flower, are as follows (Fig. 25):

1. **The calyx,** made up of **sepals,** which are green, and enclose the other flower parts in the bud.

2. **The corolla,** made up of **petals,** which are usually the colored portions of the flowers.

3. **The stamens,** each made up of a stalk at the tip of which is the **anther,** bearing **pollen grains.**

4. **The pistil,** which has a swollen basal portion, (1) the **ovary,** (2) the **style,** a slender stalk leading from the ovary, and ending in (3) a **stigma,** which receives the pollen. Within the ovary are the young **ovules** (Fig. 26), the bodies which become seeds.

The sepals and petals are often called the **non-essential** parts of the flower because they do not take part in reproduction; whereas the stamens and pistil are **essential** to reproduction. The sepals and petals protect the other flower parts in the bud, and the colored petals may attract insects.

Ordinarily, the anther is held up on a slender stalk, which brings it in a position that will better facilitate the scattering of

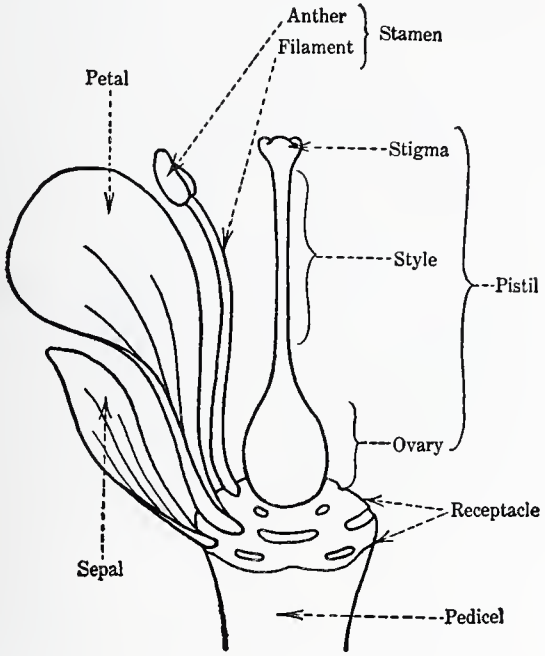

FIG. 25.—Diagram of a flower from which all but one of each whorl of flower parts have been removed. (Modified after Hall. From Holman and Robbins, in *A Textbook of General Botany.*)

the pollen by wind or by insects. When the anthers are ripe, they split open, allowing the pollen to escape. When the pollen grain is mature, it consists of a wall surrounding a mass of protoplasm, the essential parts of which are the nuclei (male or sperm nuclei) which are necessary to fertilize the ovules.

The pistil usually consists of an **ovary, style,** and **stigma.** The seeds are borne in the ovary. A cross-section of a **simple ovary,**

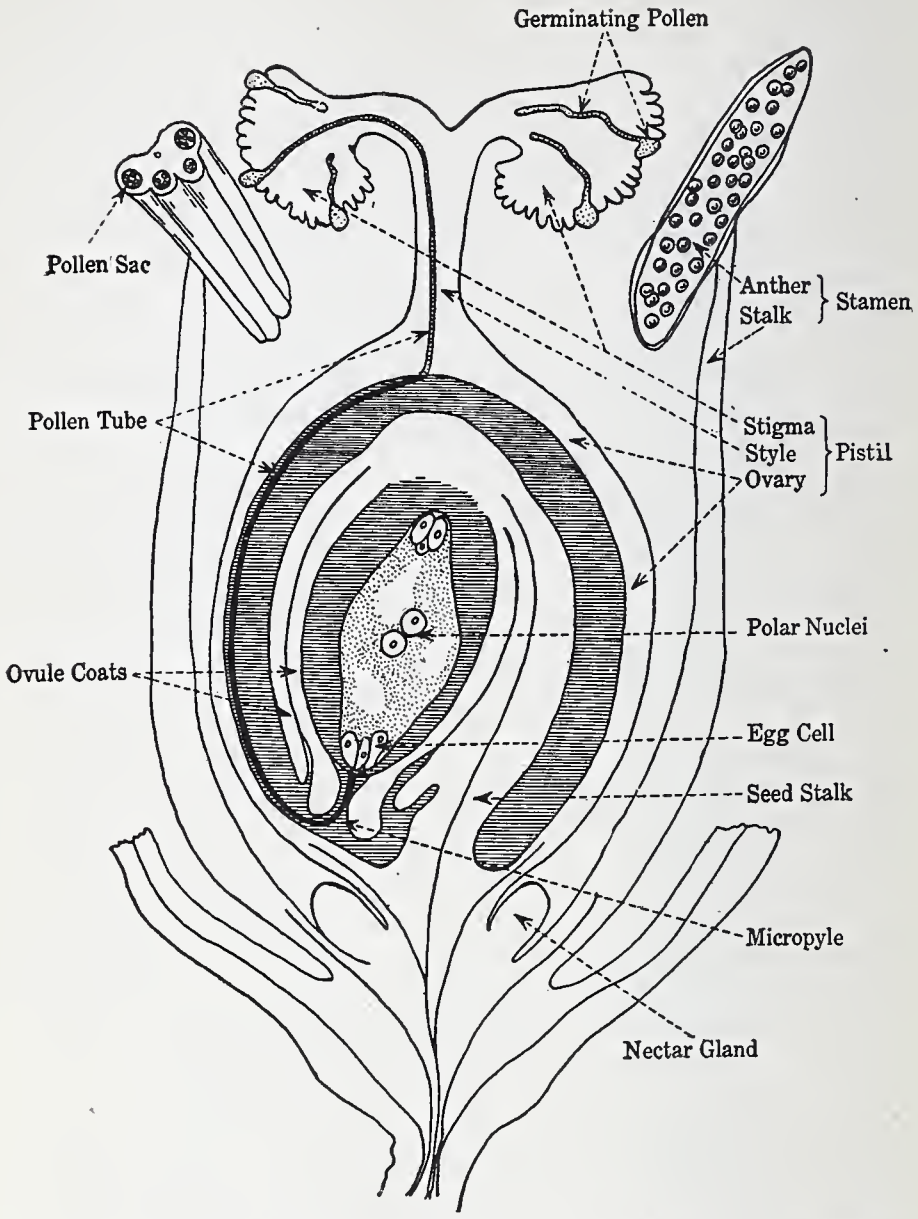

FIG. 26.—Diagram of a lengthwise section of a typical flower. (From Holman and Robbins, in *A Textbook of General Botany*. Redrawn from Sachs.)

such as that of the bean, pea, or alfalfa, usually shows it to have one chamber with one or more ovules attached to the wall. There are flowers with two or more compartments, and with one to several ovules in each (Fig. 27). Examples of such are onion, apple, orange, tomato, and cucumber.

Incomplete Flowers.—The flower just described has all four sets of flower parts present—sepals, petals, stamens and pistil. It is said to be a **complete flower.** However, one or more of these sets may be lacking, in which case the flower is said to be **incomplete.** In the buckwheat flower (Fig. 28), for example, the petals are absent. In the flowers of willows and cottonwoods, both sepals and petals are lacking. In both of the foregoing cases the essential organs (stamens and pistil) are present. However, some flowers have but one set of essential organs, either stamens, or a pistil. A flower with stamens only, and no pistil, is said to be **staminate** (male). On the other hand, a flower with a pistil but no stamens, is said to be **pistillate** (female). Staminate plants do not bear fruit and seed; only pistillate plants perform this function. Staminate and pistillate flowers may be on the same individual plant; this is the case in corn, in which the "tassel" is a group of staminate flowers, and the "ear" a group of pistillate flowers (Fig. 29). The squashes, pumpkins and melons are other examples of plants which bear staminate and pistillate flowers on the same plant. Or, staminate and pistillate flowers may be on different individual plants; examples of such plants are asparagus, spinach, hops, willows, and date palm. In these plants the flowers on any one plant are either all staminate or all pistillate. Thus we may speak of staminate (male) plants and pistillate (female) plants.

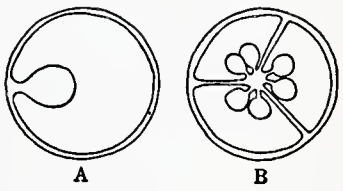

FIG. 27.—Diagrammatic cross-section of (*A*) a simple ovary and (*B*) a compound ovary.

In certain cultivated species which have male and female individuals, one of the two kinds of plants may be more desirable from the grower's standpoint than the other. For example,

in the date palm, it is desirable that most of the individuals be pistillate since these alone can bear the edible fruit. In the hop plant, it is only from the pistillate plants that the " hops " are

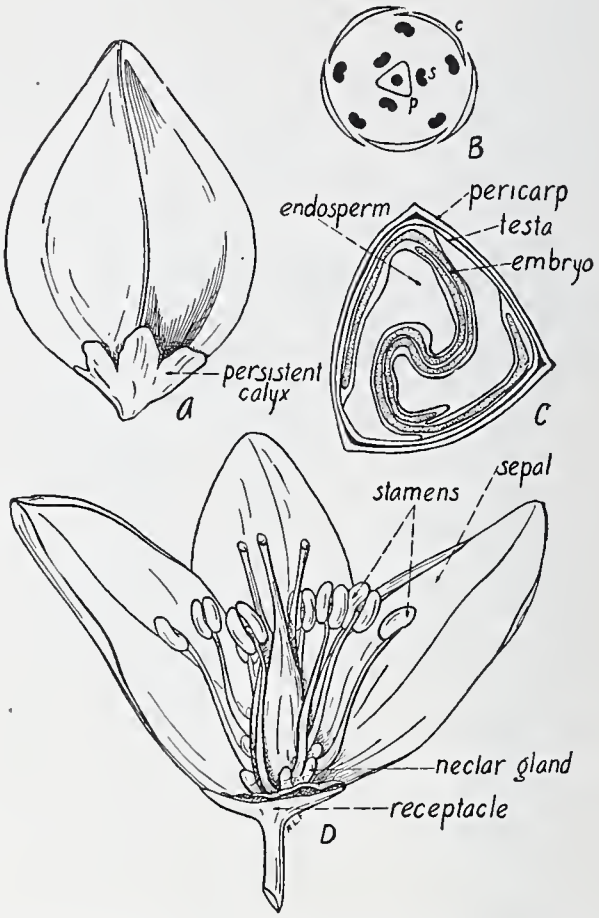

Fig. 28.—Common buckwheat. *A*, external view of mature fruit; *B*, diagram of flower; *C*, cross-section of mature fruit; *D*, flower. (From Robbins, in *Botany of Crop Plants*. *B*, after Wossidlo; *C*, after Stevens.)

obtained. In asparagus, it has been found that the yield of edible spears from staminate plants exceeds that from pistillate. Staminate cottonwoods are preferred to pistillate ones because of the " litter " caused by the cotton-covered seeds.

Some Special Types of Flowers.—The families of plants are characterized chiefly by the structure of their flowers. The

FIG. 29.—Flower groups in corn. The "ear" is a group of pistillate (female) flowers, the "tassel," a group of staminate (male) flowers. (From Robbins, in *Botany of Crop Plants.*)

vegetative structures of a group of plants may be quite dissimilar, and yet on account of fundamental likenesses in their reproductive structures, they are placed together in the same natural group.

For example, bamboo and lawn grass, although quite different in size and habit of growth, have similar flower structure, and consequently are put together in the same family (grass family, *Gramineae*). One unfamiliar with botany would not pronounce sugar beets and pigweeds as close relatives. Neverthless, examination shows that their floral structure is quite the same. Consequently, they are placed in the same family (Goosefoot family, *Chenopodiaceae*). These cases could be multiplied.

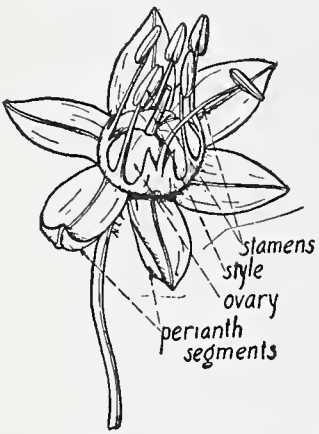

Fig. 30.—Flower of onion, a member of the lily family. (From Robbins, in *Botany of Crop Plants.*)

Let us now consider some special types of flowers.

Lily Type of Flower.—The lily family includes such well-known plants as the lily, yucca, hyacinth, tulip, onion and asparagus. In this family, **the parts of the flowers are in threes** (Fig. 30). The non-essential organs consist of six separate parts, in two circles of three each, which are usually very similar in size, shape and color. The anthers are usually large and conspicuous. The ovary is divided into three chambers, each of which usually has several seeds. Flowers of the lily type are chiefly insect pollinated.

Grass Type of Flower.—The flower (Fig. 31) of the grass family (*Gramineae*) is peculiar. It may be studied to advantage in such common grasses as wheat, oats, barley, rye, rice, corn, and sorghum. In all grasses, the flowers are in groups, each group being called a spikelet. A typical spikelet, such as that of oats or wheat, consists of a short axis, bearing a number of chaff-like bracts. The two lowermost bracts, called **glumes,** are empty, that is, do not bear flowers in their axils. Above the two glumes, are one or more bracts called **lemmas,** and usually there is a flower in the axil of each. Each flower consists of three stamens and a single pistil. The ovary contains a single ovule and has two feathery stigmas. The awns or beards of a grass are brittle-like structures usually attached to the lemmas. Inconspicuous

flowers of the grass type, with their lack of showy parts and nectar glands are wind pollinated.

Mustard Type of Flower.—The mustard family (*Cruciferae*), includes a number of familiar plants such as cabbage, turnip, rutabaga, rape, mustard, radish, watercress, horseradish, and a number of pernicious weeds, such as pennycress, wild mustard or charlock, shepherd's purse, false flax and tansy mustard. The mustard flower is characteristic (Fig. 32). It has four sepals, four petals, six stamens (two short and four long), and a two-celled

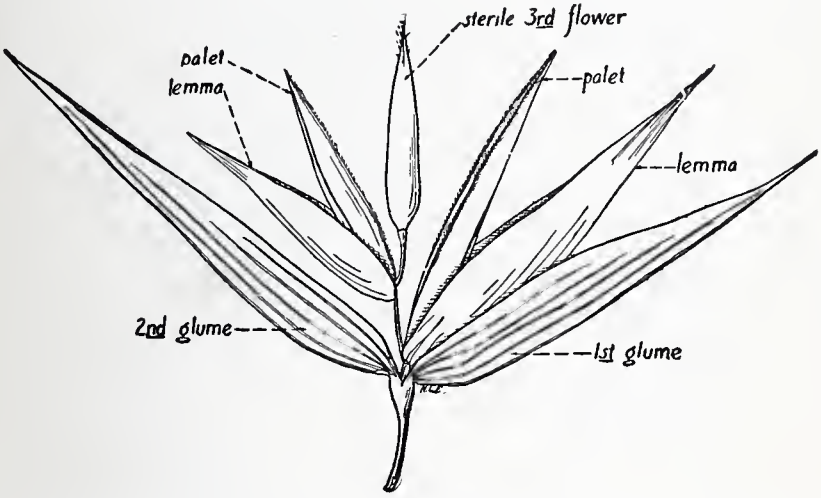

FIG. 31.—Spikelet of common panicle oats, $\times 2\frac{1}{2}$. (From Robbins, in *Botany of Crop Plants.*)

ovary. The four petals are so arranged that when one looks at the face of the flower, it has the appearance of a Greek cross, hence the name *Cruciferae* (Latin, *crux*, cross, *—fera*, to bear). The pistil has a single style with a more or less two-lobed stigma. Insects are the principal agents in the pollination of mustard-flowers.

Rose Type of Flower.—The family *Rosaceae* includes such plants as the raspberry, blackberry, dewberry, strawberry, Spiraea, rose and cinque-foil. The flowers (Fig. 33) of this family are usually perfect, except in some cultivated varieties of strawberries. There are usually five sepals and five petals. In cul-

tivated roses, however, there are numerous petals which have developed from young tissue that normally becomes stamens. There are numerous stamens, and as a rule, a number of separate pistils. The rose type of flower is chiefly insect pollinated.

Apple Type of Flower.—The apple, pear, quince, loquat, service berry, and cotoneaster, are members of the apple family (*Pomaceae*). This family bears flowers (Fig. 34) which are perfect and usually with a concave or cup-shaped receptacle, to which is attached a five-lobed or five-toothed calyx, five separate petals, numerous distinct stamens and a one- to five-celled ovary. Pollination of the apple type of flower is brought about by insects.

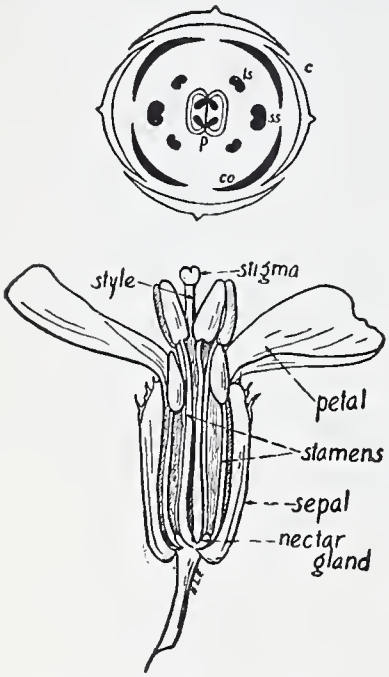

Fig. 32. — Flower of mustard. Diagram of flower above, and flower in median lengthwise section below. (From Robbins, in *Botany of Crop Plants.*)

Plum Type of Flower.—The plum family (*Drupaceae*) includes the plum, cherry, almond, peach and apricot. This is a group commonly known as the stone fruits. The flowers are perfect (Fig. 35). The corolla and calyx each have five distinct parts. There are numerous stamens. In a longitudinal section of the drupaceous flower it is seen that the ovary is placed down within a cup commonly called the "calyx tube." There is one pistil situated at the bottom of the hollow receptacle, and a one-celled ovary, usually maturing one seed. Pollination of the plum type of flower is chiefly by insects.

Legume Type of Flower.—The pea family (*Leguminosae*) is one of wide geographical distribution and possesses a great many species. Well-known representatives are common garden pea, vetch, sweet pea, clovers, sweet clovers, alfalfa, bean, cow-pea,

soy bean and peanut. The flowers (Fig. 36) are irregular in form; they have a butterfly-like shape. The calyx is usually four- or five-toothed. The petals are normally five in number, a broad upper one (**standard**), two side ones (**wings**), and two lower ones

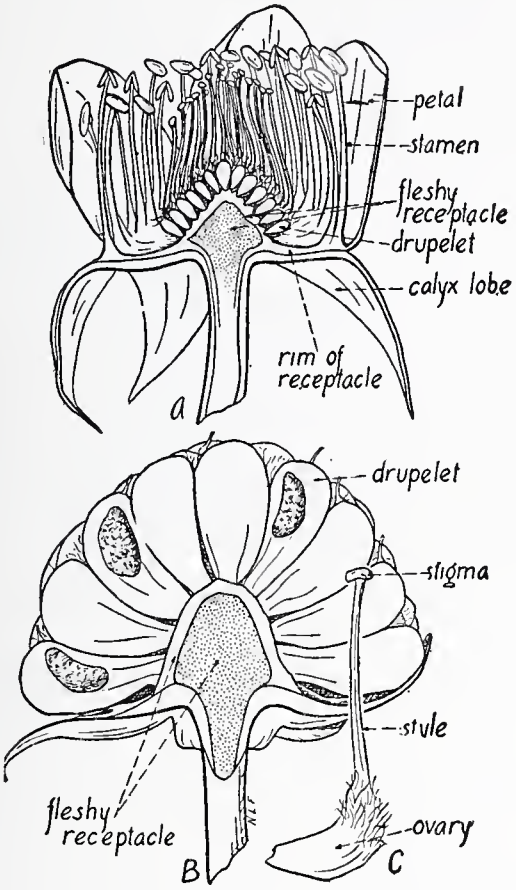

FIG. 33.—American red raspberry. *A*, median lengthwise section of flower, ×4; *B*, median lengthwise section of fruit, ×4; *C*, single immature pistil, ×5. (From Robbins, in *Botany of Crop Plants.*)

more or less united along one edge, forming the **keel**; this keel incloses the stamens and pistils. Stamens are usually ten in number, and commonly nine are united and one is free. There is a single pistil, with one cell. Some of the legumes, such as the

garden pea, are self-pollinated; many others are pollinated by insects.

Composite Type of Flower.—The thistle or composite family (*Compositae*) possesses a number of well-known plants, among which are common lettuce, Jerusalem artichoke, endive, salsify, dandelion, yarrow, sage, chrysanthemum, sunflower, golden rod, sow thistle, dahlia, aster, marigold, fleabane, everlasting, Spanish

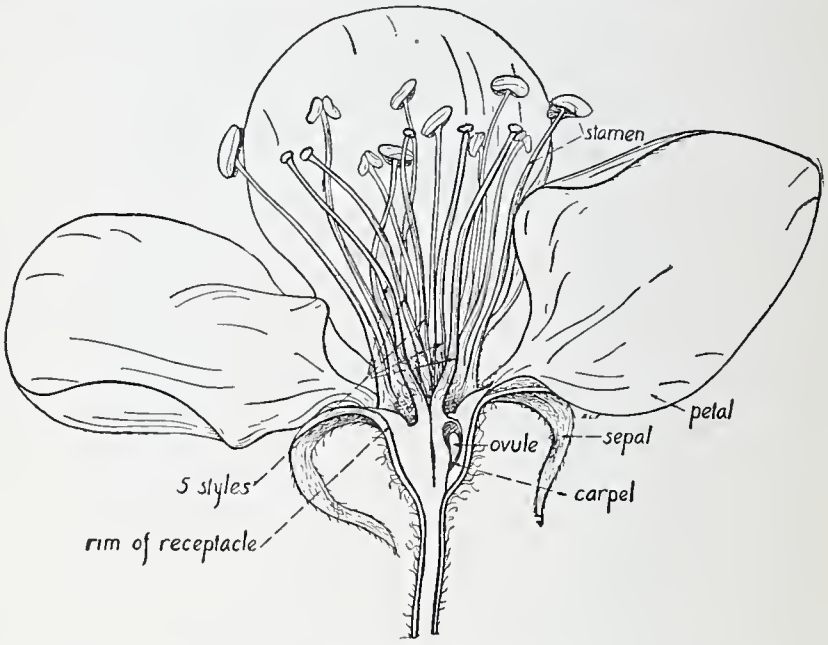

Fig. 34.—Median lengthwise section of an apple flower. (From Robbins, in *Botany of Crop Plants.*)

needles, and thistle. In this family the individual flowers are grouped to form a flower-head (Fig. 37). A " sunflower " is not a single flower, but a group of individual flowers, mounted on a common receptacle. As a rule, in the flower-head, there are two kinds of flowers: (1) those about the margin, called **ray flowers,** and (2) those in the center, known as **disk flowers.** In such composites as lettuce, however, all the flowers of a head are alike. The disk-flowers have a calyx made up of bristles or scales. These are attached at the top of the ovary. The corolla is tube-

like, and on its sides are attached the five stamens. There is a single pistil, which has a one-seeded ovary, and a single style. The ray flowers are usually imperfect. Insects are the principal agents in the pollination of composite flowers.

Double Flowers.—Many cultivated plants tend to develop double flowers. Well-known examples are forms of dahlias, chrys-

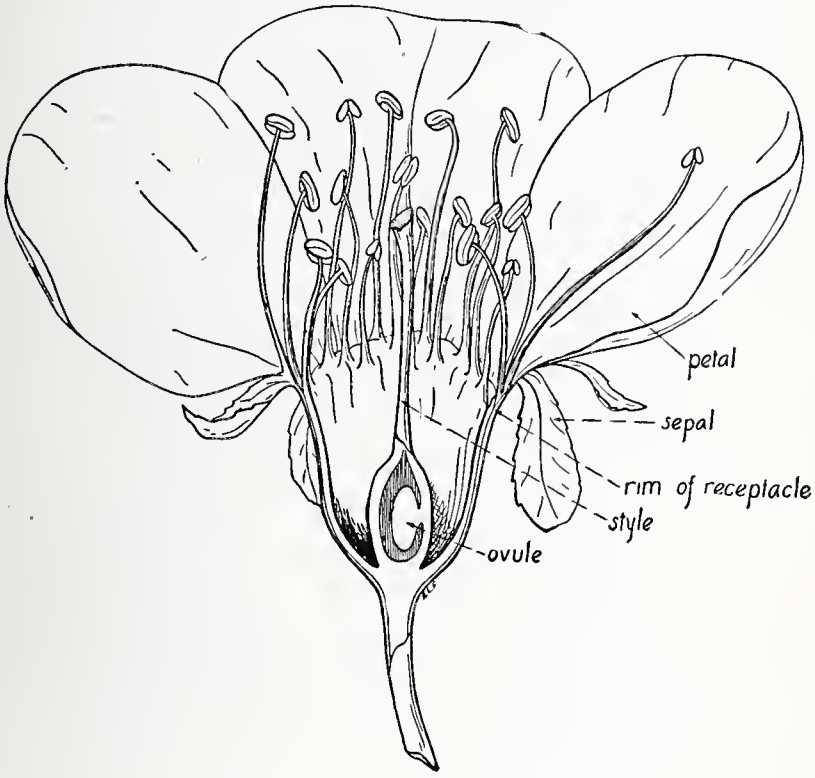

Fig. 35.—Median lengthwise section of the flower of sour cherry. (From Robbins, in *Botany of Crop Plants.*)

anthemums, pinks, roses, and hollyhocks. Doubling may arise through the change of stamens or pistils to petals, or the origin of extra petals in the circle of petals.

Pollination and Fertilization.—There are two processes associated with sexual reproduction of flowering plants which sometimes are confused. These are **pollination** and **fertilization.** A

clear distinction should be made between them. Pollination is merely a mechanical process in which pollen is transferred from an anther to a stigma. Fertilization, on the other hand, is a much more complex process, in which a **male element** (sperm nucleus of the pollen tube) unites with a **female element** (egg nucleus of embryo sac in the ovule). This union of two masses of protoplasm, male and female, is called **fertilization.** It is sexual reproduction. It is obvious that pollination might take place but the pollen tubes fail to reach the ovule and bring about fertilization.

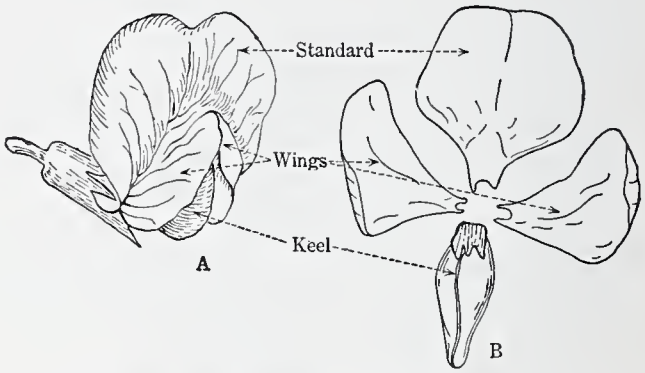

FIG. 36.—Flower of sweet pea, a member of the legume family. *A*, external view; *B*, dissected, diagrammatic.

Structure of the Ovule.—The ovule is a small spherical or egg-shaped structure in the ovary. It is attached to the ovary by a short stalk, which becomes the stalk of the seed. The mature ovule (Fig. 26), just before fertilization, consists of a central mass of tissue, surrounded by one or two coats which become the protective coats about the mature seed. These fit closely about the ovule, except at one point, where there is a very small opening, **the micropyle.**

Within the central mass of tissue is the **embryo sac,** the structure in which the embryo or young plant develops. The mature embryo sac has eight nuclei, one of which, after fertilization, develops into the **embryo plant;** two others unite with a second nucleus from the pollen tube, and the resulting body develops into **endosperm,** which is a food supply surrounding the embryo.

The remaining five nuclei soon disappear, being absorbed or disintegrating.

Structure of the Pollen Grain.—Pollen grains play a part in the formation of fruit. They are a product of the anthers. At maturity, the anthers split open and the pollen grains are dis-

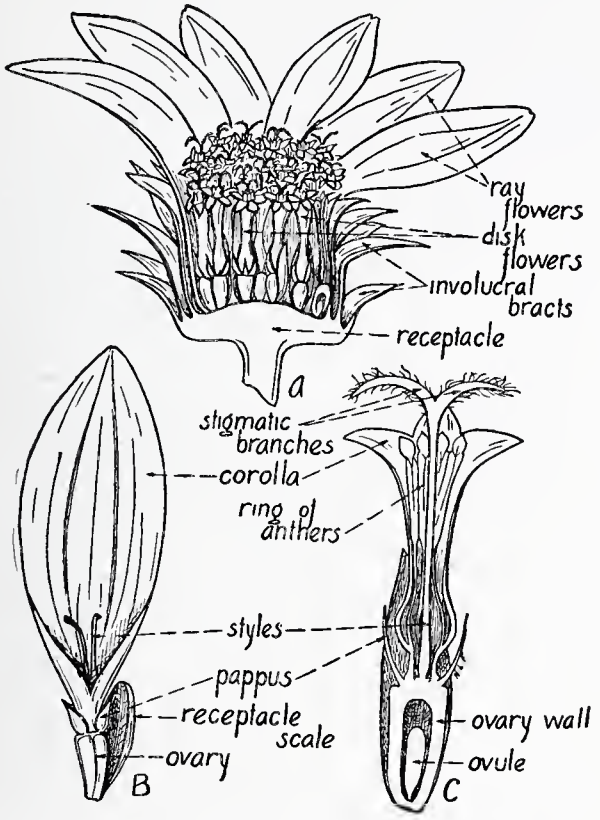

FIG. 37.—Jerusalem artichoke, a member of the composite family. *A*, lengthwise section of the flowering head, ×1; *B*, ray flower, ×6; *C*, disk flower, cut lengthwise, ×6. (From Robbins, in *Botany of Crop Plants*. *A* after Baillon.)

tributed. The pollen grains of plants vary widely in form, size, color, and particularly in surface markings. The wall of the grain usually consists of two coats, an outer thick one and an inner thin one. The wall encloses a mass of protoplasm, the essential parts of which are **three nuclei**. One of these, the tube nucleus, plays

a part in the growth of the pollen tube, the other two, sperm nuclei, fertilize certain nuclei in the ovule.

Fertilization.—Fig. 26 is a diagram of an ovary with a single ovule cut lengthwise. It shows a stage of development of the ovule at about the time when the pollen grain has reached the stigma. The pollen grain is brought to the stigma by wind or insects. It absorbs water and nutrient materials from the surface of the stigma, and grows by sending out a tube, known as the **pollen tube.** The pollen tube grows downward through the stigma and style and finally reaches the ovule. It goes through the micropyle and penetrates the ovule tissue. After the dissolving of the wall at the tip of the pollen tube, the three nuclei are discharged into the embryo sac. The tube nucleus is absorbed. One sperm nucleus unites with the egg or female nucleus to form the **fertilized egg.** Thus, this nuclear mass contains both the characters of the plant furnishing the pollen (paternal characters) and those of the plant fertilized (maternal characters). The union of the sperm nucleus of the pollen tube with the egg nucleus of the embryo sac is fertilization. The fertilized egg nucleus now develops into a young plant (embryo).

The two masses of protoplasm—the egg nucleus and the sperm nucleus—which unite are called gametes. The egg nucleus is the **female gamete,** and the sperm nucleus is the **male gamete.** The fertilized egg which results is called the **zygote. Gamete** is a general name for a sexual mass of protoplasm, and **zygote** for the body resulting from the union of two gametes. In discussions of heredity and plant breeding we hear much of these terms.

In cereals and lilies and a number of other plants, so-called **double fertilization** has been observed. One sperm nucleus has been accounted for as uniting with the embryo nucleus. The other unites with the two so-called polar nuclei of the embryo sac (Fig. 26). The body resulting from this union also carries both maternal and paternal characters. It develops into the endosperm of the seed.

Immediately following fertilization, there is a series of changes not only in the ovule, resulting in a seed, but in the ovary wall

as well. Normally, if the egg nucleus is not fertilized the ovule does not develop, but withers and dies.

Just one pollen tube penetrates the embryo sac to bring about fertilization. Many pollen tubes, even hundreds, may grow down the style, although comparatively few may function. Those which do not, wither and die. We may be sure that every ovule that develops into a seed has been visited by at least one pollen tube, and that only one pollen tube has functioned there.

Parthenogenesis.—Normally, as stated, the egg or female gamete will not start on the train of changes which result in the embryo plant unless a sperm or male gamete fuses with it. Rarely, however, the embryo develops from an unfertilized egg nucleus. This phenomenon is called **parthenogenesis.** It is a rare occurrence among plants.

Parthenocarpy.—As a general rule, lack of fertilization of the ovules is followed by the shedding of the blossoms; the ovary fails to develop completely if a good number of its ovules are not fertilized. However, development of the ovary does sometimes occur although fertilization fails. Such an unusual development is called **parthenocarpy.** With certain sorts of both apples and pears, fruits have been developed without fertilization. Of course, parthenocarpic fruit is seedless. There are among cultivated plants many which bear seedless fruit. Seedless tomatoes, egg plants, English forcing cucumbers, oranges, grapes, and bananas are quite common examples.

Dispersal of Pollen.—Pollen is carried chiefly by wind and insects. Such inconspicuous flowers as those of grasses, willows, cottonwoods, alders, birches, oaks, hickories, and pines are notable among those which have their pollen dispersed by the wind. With the exception of the nut fruits, the common tree fruits are largely dependent upon insects for the dispersal of their pollen.

In grasses the flowers are inconspicuous, they lack odor and nectar, and hence are unattractive to insects; furthermore, the pollen is light and dry, and easily blown; the stigmas are feathery and expose a large surface to flying pollen; and pollen is often produced in great quantities. For example, in corn, it is estimated that each staminate flower group (tassel) produces 20,000,000 to

50,000,000 grains of pollen. There are in the neighborhood of 45,000 pollen grains produced for each ovule. The styles, the corn "silks," are long and plumose, and are receptive throughout their entire length.

In willows, cottonwoods, alders, birches, oaks, and hickories, the flowers are in catkins. The staminate catkins are pendulous and move easily in the wind, and the light pollen is shaken from the anthers and readily carried away by the breezes. In many catkin-bearing trees the flowers open before the leaves unfold so that pollen movement is unhampered.

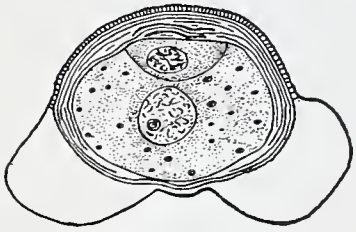

Fig. 38.—Mature pollen grain of pine. Observe the wing-like expansions which facilitate its distribution by wind; also, note the two nuclei in the body of the grain.

In pines, the flowers are also borne in short catkins, and in addition to this feature which favors wind dispersal of pollen, the pollen grains (Fig. 38) themselves are provided with two wings which assist in their distribution by the wind. In pines, pollen is produced in tremendous quantities. At the proper season, showers of pollen may be witnessed in the pine forest, and the clothing may become yellow with the pollen grains.

The principal pollinating insects are bees, the most efficient of which are the honey bee and the bumblebee. It is reported that French and sugar prunes in California and Napoleon and Black Tartarian cherries set a very light crop unless a large number of bees are present in the orchards at the time of blooming. In fact, insects are necessary for the pollination of most deciduous fruit trees except certain nuts.

The flowers of red clover must be cross-pollinated in order to set seed on a commercial basis, and the bumblebee is chiefly responsible for carrying the pollen. This insect is capable of pollinating 30 to 35 clover flowers a minute.

In many types of figs, including Smyrnas, but excepting the common black fig, all or at least one of the crops require the visi-

tation of the fig wasp, bringing with it pollen, in order that the fruit form properly.

The moths and butterflies are also important pollinating agents. They are particularly adapted with their long mouth parts to securing nectar from flowers with long tube-shaped corollas, such as larkspurs, columbine and nasturtium.

FIG. 39.—Hives of honey bees in an orchard. The insects carry pollen from flower to flower, thus bringing about a better setting of fruit. (From Division of Pomology, College of Agriculture, University of California.)

Insects are attracted to flowers chiefly by their odor and color. The former appears to be the more important influence. Many flowers have special nectar-secreting structures known as **nectaries** or **nectar glands** (Fig. 26). Sugar is the main secretion of these glands. Insects also visit flowers in search of pollen, which is used as a food mainly for the larvae.

In general, insect-pollinated flowers have both stamens and pistils in the same flower; the stamens usually have short fila-

ments, the flower groups are quite inflexible, the pollen is often sticky and produced in relatively small quantities, and the flowers are attractive due to their showiness or odor.

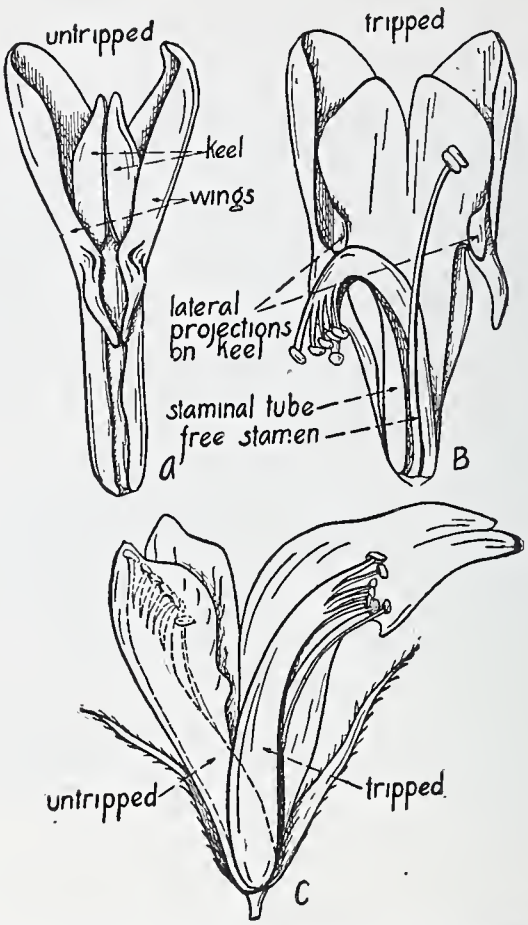

FIG. 40.—Flowers of alfalfa showing method of pollination. *A*, flower untripped, with calyx and standard removed; *B*, same tripped; *C*, position of tube of stamens, untripped and tripped. (From Robbins, in *Botany of Crop Plants.*)

Interval between Pollination and Fertilization.—In wheat, fertilization usually occurs between one and two days after pollination. This interval represents the time necessary for the pollen grain to germinate, and for the pollen tube to grow down

through the style to the embryo sac in the developing ovule. The time required no doubt varies in different varieties and under different environmental conditions, particularly temperature. Cool weather will retard germination of the grain, and growth of the pollen tube, and thus affect the " setting " of grain.

It is reported that " under favorable conditions it requires nine to thirty-two hours for the pollen tube of apples, plums, and cherries to reach the ovary when placed on the stigma or in the germinating medium. Cherry pollen requires a little over

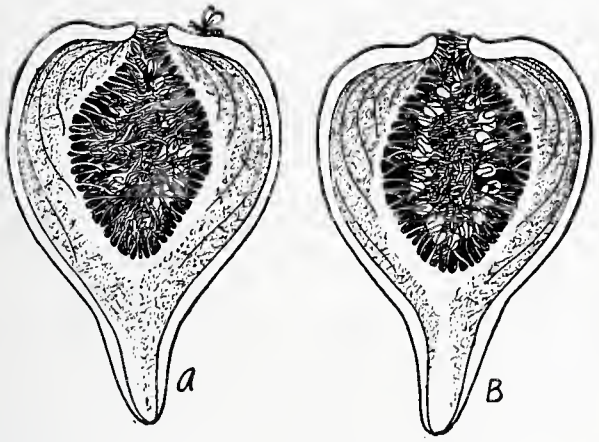

FIG. 41.—Pollination of the fig. *A*, median lengthwise section of a fig showing fertile female flowers; note the female fig wasp near the opening, also another one inside. *B*, similar section of a fig showing gall flowers. (From Robbins, in *Botany of Crop Plants*. After Kerner.)

12 hours." In pines and oaks, several months may elapse between pollination and fertilization. In Satsuma oranges the interval between fertilization and pollination is about thirty hours, whereas in trifoliate oranges it is about four weeks.

Longevity and Viability of Pollen.—Pollen varies considerably as to the length of time it will remain viable, depending upon the moisture and temperature conditions surrounding the grains, and the kind of pollen.

Corn pollen does not remain viable much longer than twenty-four hours after shedding. That of *Hibiscus trionum* lives no longer than three days. Pollen of the date palm will retain its

viability for several months, if kept dry. The longevity of apple pollen has been variously reported by different investigators. One worker records germinations of 12, 10, 5, and 8 per cents for different lots after seven months of storage in the laboratory, with a temperature ranging from 50° to 65° F. The pollen of apple and plum remains alive much longer if stored in closed vessels which prevent drying out than when stored in the open. The pollen of some plants, such as the sugar beet, alfalfa and red clover, absorb water rapidly and burst in water or in a saturated atmosphere. Such pollen loses its viability rapidly in an atmosphere of high relative humidity.

Dry pollen will withstand greater temperature extremes than moist pollen. However, resistance to low temperature is also a specific character. For example, pollen of apple, pear and plum will withstand freezing temperatures ranging from 33° to 34° F., whereas about 50 per cent of peach and apricot pollen grains are killed by this temperature.

Kinds of Pollination.—Pollen may be transferred from an anther to a stigma of the same flower or of another flower on the same individual plant. These two cases are termed **close-pollination.** Again, pollen may be transferred from an anther to a stigma of a flower on another individual plant. This is **cross-pollination.**

If **close-pollination** is followed by fertilization, the flower is said to be **close-fertilized,** or **self-fertilized.** If **cross-pollination** is followed by fertilization **cross-fertilization** is said to have taken place.

Self-fertilization is the rule in most cereals except rye and corn. These two cereals can not be self-fertilized without a reduction in vigor and productivity. It should be pointed out, however, that although wheat, oats and barley are usually self-fertilized, a certain small amount of crossing does take place under field conditions. Self-pollination means that there is little danger that a pure strain will become impure through the introduction of characters brought in by the pollen grains of undesirable strains.

Self-pollination, and consequently self-fertilization, is avoided

in plants by many different devices. For example, in the beet, red clover, and many other plants the anthers of a flower shed their pollen before the stigma of that flower is receptive.

Misshapen Fruits.—There are many causes of misshapen fruit, a number of which are concerned with fertilization. The parthenocarpic (seedless) fruits of the pear are abnormal in shape (Fig. 42). In the tomato, a scanty supply of pollen on the stigmas may result in small and deformed fruit; one-sided tomatoes result when pollen falls upon one side of the stigma only. In the strawberry, non-fertilization or incomplete fertilization is usually indicated by berries with hard, greenish, undeveloped tips, so-called "nubbins." Frost injury is also often a cause of misshapen fruit.

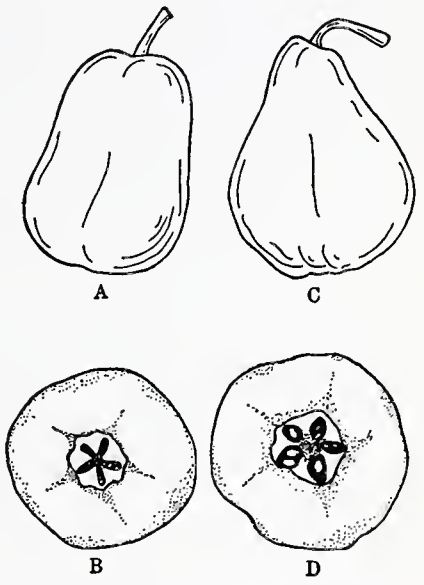

FIG. 42.—*A* and *B*, Bartlett pears which were self-pollinated; the fruit is abnormal in shape and seedless; *C* and *D*, Bartlett pears eross pollinated with Winter Nelis; the fruit is of normal shape and bears seeds. (Redrawn from photograph by Division of Pomology, College of Agrieulture, University of California.)

Failure of Blossoms to Set Fruit.—The failure of orchard trees to set fruit, in spite of the fact that an abundance of blossoms is produced, is due to one or more of several causes. Among these causes may be mentioned the following:

1. *Pollen is not shed at the time when the stigmas are receptive.* The pollen may be shed before, or after, the stigmas are receptive. In some American plums, particularly during periods of cold weather, the stigma may pass the receptive condition before the pollen is mature.

2. *Pollen is not viable.*—Some cultivated varieties of grapes bear impotent pollen. Most of the varieties of grapes with sterile pollen have stamens that are reflexed. Certain varieties of straw-

berries (Glen Mary and Crescent) produce impotent pollen, and hence are self-sterile.

3. *Imperfect Flowers.*—There are some varieties of strawberries which have only pistillate flowers. Consequently, if such a variety is planted by itself, there will be no pollen. In planting

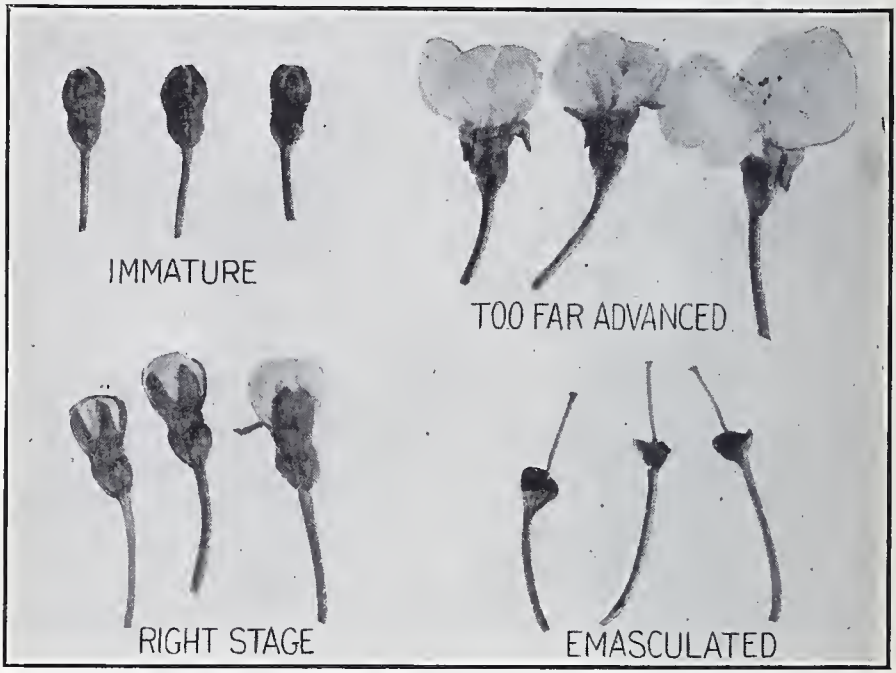

Fig. 43.—Artificial pollination. Emasculated cherry blossoms, and proper and improper stages of development for the emasculating operation. (From Division of Pomology, College of Agriculture, University of California.)

varieties with pistillate flowers only, it is necessary to have rows nearby planted to pollen-bearing individuals.

4. *Self-sterility.*—Many varieties of orchard fruits are not capable of setting fruit unless pollen from another variety is used. That is, they are self-sterile. For example, the Montmorency cherry is self-sterile but may be cross-pollinated by Early Richmond or English Morello. In some states the Spitzenburg apple is self-sterile but can be fertilized with pollen from a number

of other varieties, such as Yellow Newton, Arkansas Black, Jonathan, and Baldwin. Evidently, the mutual affinities of varieties must be considered in setting out an orchard. It would not be well to plant solid blocks of Spitzenburg apple, for example. There should be here and there in the orchard, trees of some one of the other varieties, the pollen of which is capable of fertilizing it.

Self-sterility in pears is the reason for the barrenness of many pear orchards. It has been frequently observed in many parts of the country that when a certain variety of pear was planted in a solid block, there was often a pronounced failure to set fruit. This is particularly true, it seems, of Bartlett and Kieffer pears. These varieties give much better results when they are planted with such varieties as Lawrence, Duchess and Anjou.

Self-sterility also occurs in certain plums, and in a number of other kinds of fruits.

5. *Unfavorable Weather Conditions.*—Fruit-setting may sometimes fail because of frost or because of cold, rainy weather which interferes with the movement of insects, or delays the growth of the pollen tube; or hard rains which come immediately after the pollen is brought to the stigma, may wash the grains from the stigmas. In the case of corn, hot dry winds may wither the "silks," and make it impossible for the pollen to stick to them and germinate; as a result there is an incomplete "filling" of ears.

6. *Lack of Pollinating Insects.*—In most of our orchard trees the pollen is carried by insects, chiefly bees. It has been shown that under certain conditions the percentage of flowers setting fruit can be increased by placing bee hives in the orchard. It is usually considered that one hive of bees to one or two acres of orchard is sufficient.

Artificial Pollination.—One of the chief means of improving plants is by crossing, that is, hybridizing. This makes necessary the operation of artificial pollination.

Pollen must be collected from flowers which have not yet opened; if it is collected from open flowers, bees may have visited them and left undesired pollen sticking to the anthers, and hence

there would be a mixture of pollen. The flowers to be pollinated must have their anthers removed also before they are open (Fig. 43). Otherwise, the stigma may have had pollen brought to it, from other flowers or from anthers of the same flower. In removing the anthers of a flower, care must be taken that there is no injury to the stigma, style or ovary. After removing the anthers of the flower to be cross-pollinated, it is necessary to place a bag

FIG. 44.—Equipment used in process of artificial pollination: camel's-hair brush, vial containing pollen, and metal ring, bearing data, to be tied to flower pollinated. (From Division of Pomology, College of Agriculture, University of California.)

over it to prevent undesirable pollen being carried to it by wind and insects (Fig. 45).

In collecting pollen, whole unopen flowers may be placed on a sheet of paper in the sunlight until the anthers split open and shed their pollen. The pollen should be kept dry. It may be stored in glass vials, plugged with cotton, or in quinine capsules, or in small paper bags. It is best to use the pollen within two or three

days, but many kinds of pollen will remain viable for days or even weeks, if kept in a cool, dry place. When the stigmas of the bagged flowers are receptive, the bags are removed and the pollen applied to them with a small camel's hair brush. A receptive stigma usually has a glistening appearance. After the pollen is applied, the bag is returned to the flower, and left there until the stigma

FIG. 45.—Artificial pollination. The flowers to be cross-pollinated are emasculated, and then kept covered with a bag, until the pistils are pollinated and the stigmas have passed the receptive stage. (From Division of Pomology, College of Agriculture, University of California.)

withers and all danger from the influence of strange pollen is passed.

Inbreeding and Hybrid Vigor.—It is a common observation that when certain plants are self-fertilized, that is, **inbred,** there results a loss of vigor. This is well illustrated in the case of corn, in which the progeny of self-fertilized plants is inferior in size, vigor and productiveness as compared with the offspring of cross-bred plants. Moreover, it has been observed that when these

"run out," inbred plants are crossed with another inbred group, the progeny has the vigor, size and productiveness of plants

FIG. 46.—The result of seven generations of inbreeding. The original parent is shown at the right, and typical representatives of seven successive generations shown in order from right to left. (From Jones and Mangelsdorf in Conn. Agr. Expt. Sta. Bulletin No. 273.)

that were never self-fertilized. The loss of vigor resulting from inbreeding is not permanent, but can be regained by crossing.

CHAPTER XII

THE SEED, SEED GERMINATION, AND SEED TESTING [1]

Seeds are of extreme economic importance, chiefly because they are food-storage organs. Man uses seeds as a means of multiplying useful plants. In our ordinary agricultural operations, the seed is usually the beginning of the crop. Seeds also furnish man with a large proportion of his food, and many important products used in the industries. Consider the tremendous importance of wheat, rice, corn, barley, oats and rye as foods. A large part of the world's supply of flour is made from wheat. Rice is a food for more human beings than is any other grain. It is the principal food of the densely populated regions of China, India, and the neighboring islands. No other cereal is put to such a variety of uses as is corn. Corn meal is one of the chief forms in which the grain is used as a food for man. Corn oil is obtained from the embryo. About 50,000,000 bushels of corn are used annually in the United States in the manufacture of commercial starches. Glucose, grape sugar and artificial gums are made from corn starch. The greatest use of the barley grain is in the preparation of malt. Large quantities of oats are consumed annually in the form of rolled oats or oatmeal. Rye is of importance in the making of flour and as a stock food. Also consider the great value of the oil-bearing seeds such as the cocoanut, cotton, flax, castor bean, and peanut.

In this chapter the reader will find a discussion which will throw light on the following questions: What are the conditions necessary for the germination of seeds? Why is it advisable to compact the soil over the seed after it is planted? What are the so-called " hard-seeds " of alfalfa and other legumes? How can their percentage germination be improved? What determines the depth to which seed can be planted? Do vigorous plants

[1] In this chapter free use has been made of material which appeared in publication by the author from the Colorado Agricultural Experiment Station.

produce better seed than weak ones? Under what conditions do seeds mature the best? What are the best storage conditions for seeds? How long will seeds live? Why is it that some seeds will not germinate well immediately after they are harvested? How may the germination of seeds be hastened? How does size of seed affect yield? How do you compute the actual planting value of seed? What are the methods for the home testing of seeds? What diseases are carried by seeds? How can seed be disinfected?

All Seeds are Produced by Flowers.—We have learned that **the flower is the seed-forming organ of the plant.** However, not all parts of the flower are concerned in seed production. The more or less showy petals and sepals of the flower have nothing to do in the production of seed. They wrap about and protect the other organs of the flower. The organs essential in seed formation are the stamens and the pistils. If we watch the growth and development of the flower from the time it opens until seeds are produced, we see that seeds are formed in the pistil; furthermore, we note that the anthers wither after the pollen from them is shed, and it usually happens that the petals fade and fall off. Normally, seeds will not form in the pistil, if the pollen is prevented from coming to it. This may be shown by the simple experiment of cutting off the anthers of the flower before they open to shed their pollen, and covering the flower with a paper sack to prevent pollen from being brought in from other flowers. As we have seen, in the swollen base or ovary of the pistil is the ovule, which becomes the seed. From the ovary there arises a long stalk or style at the tip of which is a slightly enlarged portion, the stigma. The stigma receives the pollen. When the stigma is ripe for pollen, it usually becomes sticky. A glistening, sticky appearance of the stigma shows that it is ready to receive pollen.

We have seen that the pollen grains are brought to the stigma of the pistil by various agents, chief of which are wind and insects; that they germinate and grow readily on the stigma; that each pollen grain sends out a thin-walled tube, the pollen tube (Fig. 26), which grows down through the style and comes

to the ovule in the ovary; that each ovule forms a seed only after the egg cell within it has united with a nucleus of the pollen grain; and that the seed results then from the union of two elements, one in the ovule, and one in the pollen grain. Immediately following fertilization, the ovule begins to undergo changes which result in a seed. Seeds then are formed in the ovary of the pistil of a flower. We may never expect to find seeds on any part of the plant other than the flowers. Furthermore, seeds are formed as a result of the union of a part of the ovule with a part of a pollen grain.

We learned that the embryo sac in the ovule has a number of nuclei (Fig. 26), one of which is the egg or female nucleus; that it is this female nucleus which unites with one of the sperm or male nuclei from the pollen grain, the body resulting from this union becoming the young plant. As stated above, it has been found that in some plants one nucleus of the pollen grain unites with a second nucleus of the embryo sac, and that the body resulting from this second union in the embryo sac develops into the endosperm of the seed. The endosperm is composed of stored food material and may totally or partially surround the embryo. The grains of wheat, oats, barley, rye and other grasses contain an abundance of endosperm. In fact, the cereals are cultivated chiefly for the large amounts of starch and protein stored in the endosperm of the seed. In some seeds there is almost no endosperm; for example, the seeds of beans, peas, alfalfa, clover, etc. In these, the food material is stored in the embryo itself, and not outside of it.

We have now traced briefly the development of the young plant or embryo and the endosperm of the seed. The coverings of the ovule also change considerably as the seed matures. They become drier, harder and of greater protective value to the underlying parts. The seed coat protects the young plant or embryo from mechanical injury, from sudden changes of temperature, but particularly from drying out. It is well known that seeds may lie about for years and lose but little water. If the seed coats are but partially removed the young plant within soon dries up.

Fruit and Seed Distinguished.—A fruit is a matured ovary, with its seeds, and any other part of the flower which may be closely associated with it. The fruit contains the seed or seeds. For example, the entire bean pod is a fruit; the beans within are the seeds. It is in the case of dry, one-seeded fruits particularly that distinction needs to be made between the fruit and seeds. For example, the buckwheat fruit (Fig. 28) or grass fruit (grain) is commonly called a " seed." But, if their development is traced

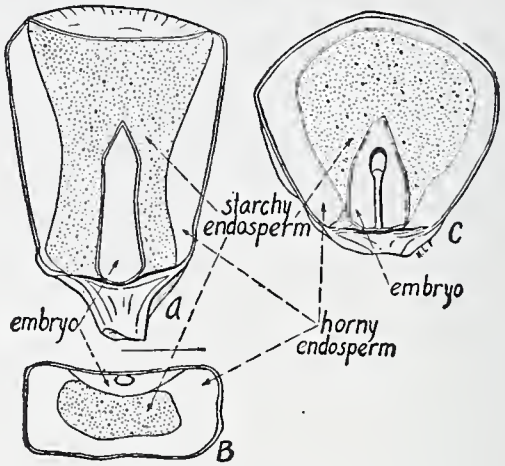

FIG. 47.—Grain of corn. *A*, median lengthwise section, cut parallel to broad surface, of grain of dent corn; *B*, cross-section of the same through the embryo; *C*, section as in *A* of flint corn. (From Robbins, in *Botany of Crop Plants.*)

and their structure carefully examined, they are seen to be true fruits, with a very thin ovary wall enclosing **one** seed.

The Structure of the Seed.—The essential part of a seed is the young plant or **embryo.** As stated, this young plant is surrounded by **protective layers** (seed coats) and often is accompanied by a supply of stored food material. The stored food material enables the embryo to start growth and to maintain itself until it gets above ground and develops organs with which to make food. The endosperm may be lacking or very abundant. The embryo may be small or large. In the grain of corn or wheat the endosperm forms the larger proportion of the grain (Fig. 47).

In the bean, pea, alfalfa and clover seed the endosperm is almost lacking and the embryo fills most of the space within the coat (Fig. 49).

Let us examine a common bean seed. Near the middle of one edge is a large oval scar. It is called the **hilum** (Fig. 48). It marks the place where the seed broke from the stalk which attached it to the wall of the pod. At one end of the hilum is a small opening, the **micropyle.** The micropyle is an opening in the coat, through which, in the ovule, the pollen tube enters; and in the mature seed the first root of the plant protrudes at the time of germination.

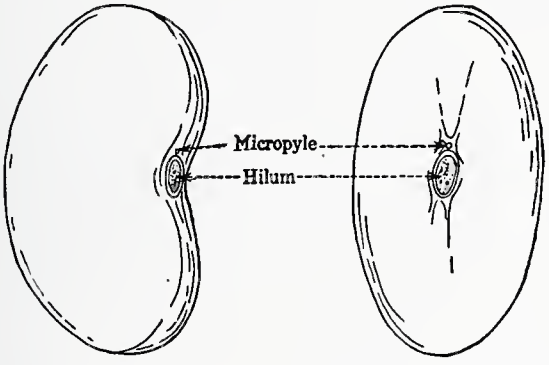

Fig. 48.—The seed of common bean showing two external views.

The micropyle is more easily seen if the seed is soaked in water.

The seed coats, or skin, of the bean, may be easily removed from the seed when it is soaked in water. Having removed the seed coat, the large embryo of the seed is seen. This embryo consists of the following parts (Fig. 49): (1) two cotyledons or seed leaves; (2) the young foliage leaves between which is the first bud; (3) the root. The two cotyledons are large and fleshy and contain stored starch. The two first foliage leaves are folded together. Although small, the veins within them can be easily seen.

Seeds vary a great deal in shape, size, color and surface markings. By a study of these external characters one may come to know the various economic and weed seeds. There are a number of weed seeds which are often associated with and may

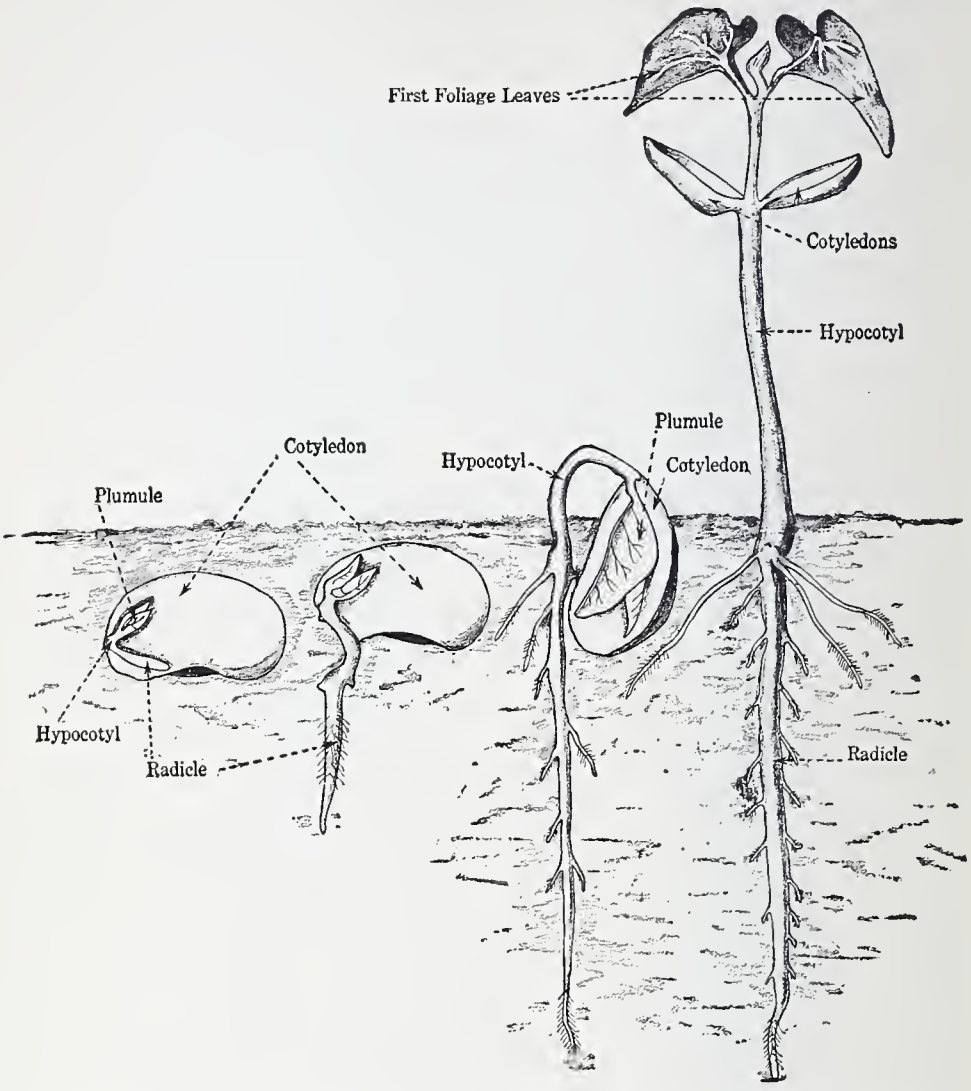

FIG. 49.—Stages in the germination of the seed of a common bean. In each of the first three stages one of the cotyledons (seed leaves) has been omitted from the drawing. (From Holman and Robbins, in *A Textbook of General Botany*. Redrawn from Coupin.)

be easily mistaken for certain field seeds. For example, the seeds of alfalfa, yellow trefoil, white and yellow sweet clover and dodder have very much the same appearance and may be very easily confused. However, careful study shows that they differ in their external characters and can be distinguished.

The Germination of the Seed.—We have seen that the mature seed contains a small **living plant,** called the embryo or " germ." This young plant is in a resting or dormant condition. Under proper conditions of **moisture, temperature** and **supply of oxygen,** the embryo starts to grow. This growth of the embryo, with the accompanying bursting of the seed coats, is called **germination.** Germination is completed when the young plant has developed far enough to lead an independent life, that is, does not derive nourishment from food stored within the seed.

Water and Germination.—The conditions essential to germination are moisture, warmth, and free oxygen. Water softens the seed coats and makes it possible for the young sprout to break through them more easily. Water also facilitates the entrance of oxygen into the seed, for when the seed coats are wet, oxygen will diffuse through them more readily than when they are dry, and too, carbon dioxide which is given off in the respiration of the living cells of the embryo, can diffuse outward more easily. The secretion of digestive fluids, the digestion of stored foods, the movement of foods, in fact, all activities of the cells of the seed proceed only when they are well filled with water. Seeds which are old will not stand as much water as vigorous, fresh seed. In handling old seeds, care must be taken to apply the water to them gradually and uniformly; variations in the amount of water are injurious. Seeds will endure greater extremes of temperature when they are dry than when moist.

Temperature and Germination.—No less essential to seed germination than water is a certain degree of warmth. The temperature which is the most favorable to germination is not the same for the different kinds of seeds. Moreover, the highest temperature and the lowest temperature at which seeds germinate vary. For example, it is quite well known that cucumbers and melons require a higher temperature to germinate properly than

wheat and barley, and some other small cereals. The seeds of "cool season crops," such as peas, lettuce, radish, and small cereals, will germinate readily at 50° to 60° F., while corn, pump-

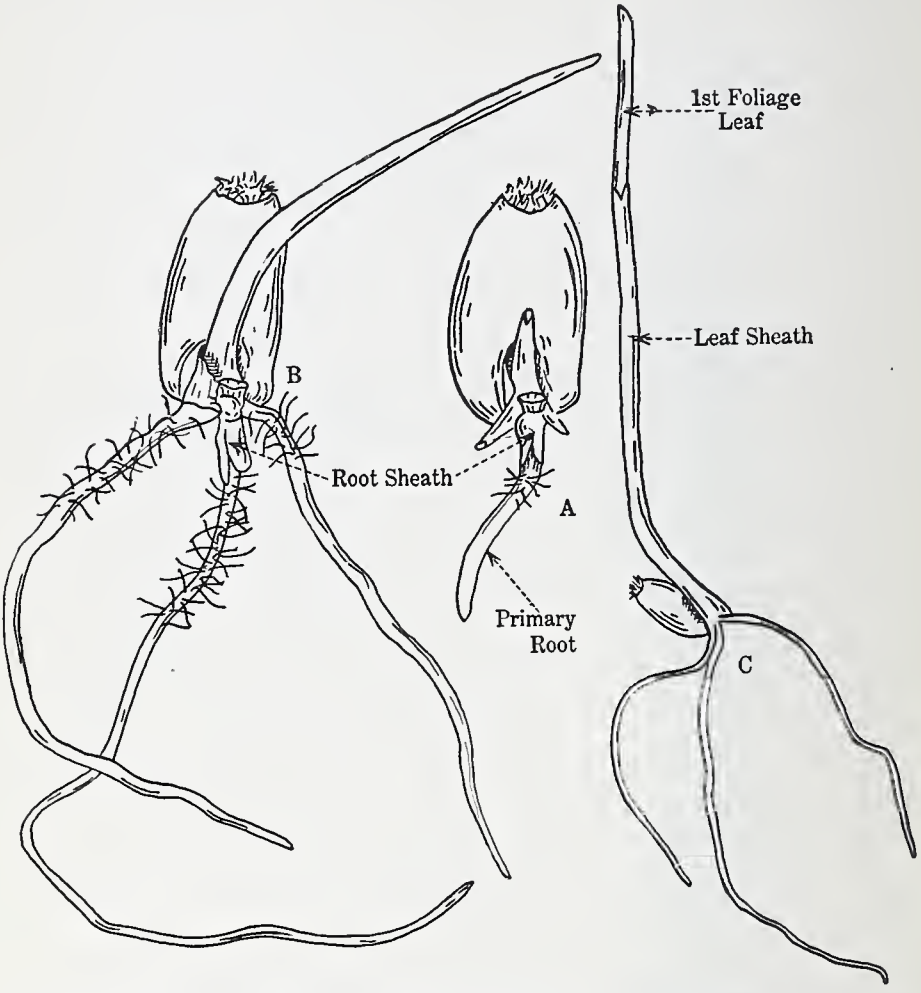

Fig. 50.—Three germinating stages in wheat. (From Robbins, in *Botany of Crop Plants.*)

kin, cucumber, egg plant, and other "warm season crops" require a temperature of 70° to 80° F., to give fairly rapid germination. It requires from ten to twelve days for corn grains

to germinate at a temperature of 49° F., whereas at 80° F., they will germinate in two days.

The lowest temperature at which seeds can germinate is called the **minimum temperature;** the temperature at which they germinate quickest, the **optimum;** and the highest temperature at which they can germinate is the **maximum.** These three temperatures for a number of different kinds of seeds are shown in the following table:

	Minimum. deg. F.	Optimum, deg. F.	Maximum, deg. F.
Barley	32–41	77–88	88–99
Clover (red)	32–41	88–99	99–111
Cucumber	60–65	88–99	111–112
Corn	41–51	99–111	111–122
Flax	31–41	77–88	88–99
Alfalfa	32–41	88–99	99–111
Melon	60–65	88–99	111–122
Oats	32–41	77–88	88–99
Pea	32–41	77–88	88–99
Rye	32–41	77–88	88–89
Wheat	32–41	77–88	88–108

From 60° to 80° F. is satisfactory for the germination of most seeds of temperate regions. The temperature of the soil is referred to here, rather than the temperature of the air. When the soil is cold and moist, seeds should not be planted as deep as when it is warm and moderately dry.

Oxygen and Germination.—It must be kept in mind that all living cells of the seed must respire in order to maintain life, and that some oxygen is necessary in this process. In the resting stage, the seed requires very small amounts of oxygen but when germination starts it demands a greater amount. That germinating seeds respire actively is shown by the large quantities of carbon dioxide they give off, and also by the heat liberated in the process. A mass of germinating seeds of barley, or other seeds which ger-

minate rapidly, may actually become heated until they feel warm to the hand. Even though there is sufficient water and warmth, unless seeds are planted so that free oxygen can reach them, they will not germinate. If seeds are planted too deep in a heavy clay soil, or in a soil that is too wet, they are quite likely to have a poor supply of oxygen and to germinate slowly. It is true that some seeds, those of rice, for example, will germinate with a very

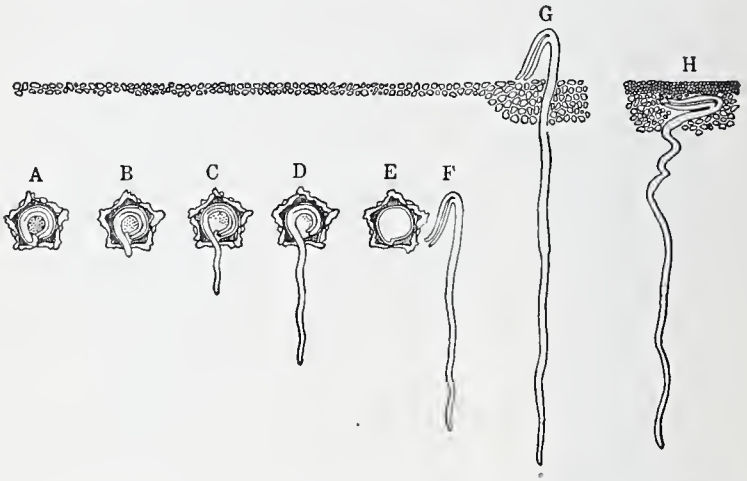

FIG. 51.—Stages in the germination of sugar beet seed. In stages *A* to *D* the young plant is in contact with stored food, and draws upon this in its growth; in *F* the young plant has become pulled away from the seed and has no connection with a source of food. It must now shift for itself. Not until the plant reaches the ground surface is it capable of making food. *H*, a crust on the surface of the soil may prevent the young seedling from coming to the surface, and as a result it dies from starvation.

small amount of oxygen, even with that which occurs in water. But, if the water is boiled before the rice seeds are placed in it, and the surface of the water is covered with a thin film of oil to prevent the absorption of oxygen by the water, the seeds fail to germinate.

Light and Germination.—A number of seeds germinate better in the light than in the darkness. The best known example of such a seed is Kentucky blue-grass. Most seeds, however, will

germinate as well in the light as in darkness, if they have the proper amount of water, heat and oxygen.

The Process of Germination.—*The Absorption of Water.*—The first stage in the process of germination of the seed is the **absorption of water.** The rate at which seeds absorb water from a soil depends chiefly upon the water content of the soil, the compactness of the soil, its temperature, and the character of the seed coats. A soil may be so dry that the seed does not absorb enough water to germinate, but remains in a dormant condition. Although a seed may absorb water very rapidly from a very wet soil, it will not necessarily grow as rapidly in such a soil. If a soil is very wet, it means that the oxygen supply in it is low, and oxygen is as essential to the growth of the embryo as is water.

It is the common practice to compact the soil over the seed after it is planted. This brings the moist particles close about the seeds, and increases the points of contact between them. This object is attained by the use of the press wheel on planters. Seeds absorb water more rapidly from a warm soil than from a cold one.

"*Hard Seeds.*"—Although most seeds have coats which permit the ready intake of water, there are seeds such as those of alfalfa, sweet clover and other legumes, the coats of which are almost impermeable to water. Such seeds are called "hard seeds." They will not grow readily, even when placed under perfect conditions for germination. Hard seeds are not necessarily poor seeds. Some of them will germinate in several weeks; some will remain in the ground for an indefinite period without germinating. Unhulled sweet clover seed may often have as much as 85 per cent hard seed. Hulled sweet clover has a lower percentage of hard seed than the unhulled.

It is claimed that a larger percentage of hard seeds is produced in dry climates or when ripening takes place under dry seasonal conditions than in moist climates or moist seasons.

The permeability of leguminous seeds can be increased by "scarifying"; that is, passing them through a machine that scratches the surface. The ordinary alfalfa huller is effective for this purpose, as is shown by experiments; alfalfa grown under

a variety of soil and climatic conditions had about 90 per cent of hard seeds if hulled by hand, and only about 20 per cent if hulled by machine. Various types of scarifying machines are on the market. Scarifying, or abrasion of the seed surface, is accomplished by blowing the seed over garnet paper. The following results from using this machine with sweet clover seed have been recorded:

Seed not scarified.....30 per cent germination
Seed scarified.....87.6 per cent germination

Digestion of Stored Food and Its Transfer. The second stage in the germination of the seed is the **digestion of stored foods,** and its **transfer** to the growing points of the young plant (embryo). Certain cells of the seed secrete digestive juices which act upon the stored foods, render them soluble, and make possible their movement to the growing points of the roots and stem. As the young plant grows, the stored food in the seed is used up. It is important to keep in mind that all of the early growth of the young plant is made wholly at the expense of this stored food. However, not all the reserve food enters into the plant substance of the seedling, but a portion of it is lost in respiration. It is not until the roots are established in the soil, and the leaves are green, that the plant is capable of making its own food, and leading an independent life.

The depth at which a seed can be planted safely depends somewhat upon the amount of food stored within it. Many small seeds, such as those of tobacco, are planted on the soil surface; large ones may be planted more deeply. If a seed is planted so deeply that its reserve food supply is consumed before the plant reaches the light, the plant will die from starvation. Seeds should not be planted deeper than is necessary to insure a proper amount of moisture.

The swelling of the seed caused by the absorption of water, and the growth of the embryo cause a breaking open of the seed coat. The young root is usually the first part of the embryo to protrude. The cotyledons may remain in the soil or may be

brought above the soil. The single cotyledon in all grains remains in the soil. The cotyledons of peas also remain underground. But in such seeds as bean and squash, the cotyledons are brought above ground and become the temporary leaves. Being exposed to the light, they may become green and aid in the food-making process. After a time, however, all of the food that has been stored within them is absorbed by the growing seedling and they shortly wither and fall off.

Conditions Affecting the Vitality of Seed.—It is a common observation that when a lot of seeds is planted under the most favorable conditions for germination a number of them fail to germinate. Some seeds are quick to germinate and form strong, vigorous seedlings. Others sprout but slowly and the young plants are weak and sickly. The farmer wants seeds which have a power to germinate readily and produce vigorous sprouts. In other words, he wants seeds of high vitality.

There are many conditions which influence the vitality of seeds; these are discussed in the following paragraphs:

1. *Vigor of the Parent Plant.*—Seeds from strong vigorous parent plants usually have larger embryos and a greater amount of food reserve that those from weakly parent plants. In the selection of seed for planting, strong healthy mothers should be considered.

2. *Conditions to which the Seeds are Exposed While Developing.*—The vitality of the seed is influenced by the temperature of the air and the amount of moisture in the air at the time the seed is maturing. Most seeds mature best under dry atmospheric conditions, and with moderately high temperature. Low temperatures early in the autumn may injure the partly mature seed. Corn, for example, suffers from freezing before the grain is thoroughly dry. The tissue of the grain is broken down by the freezing of the water in it. If the grain becomes thoroughly dried, it will withstand very low temperatures. Corn containing 13 per cent moisture may be stored with safety in bins exposed to temperatures much below freezing.

3. *Maturity of the Seed.*—Although seeds will often germinate when they are not fully ripe, the plants from such are frequently

weak. Lack of maturity or low vitality in corn is usually indicated by soft ears, by any discoloration of the grain, especially at the tips, and by blisters on the skin. Immature corn quickly loses its germinating power.

4. *Conditions under which Seeds are Stored.*—Seeds should be stored under conditions that are uniformly dry and cool. If the atmosphere is moist and warm, germination may be started, and in case it is, the respiration rate of the live cells is increased and the seed uses up a certain amount of its stored food. Its energy is thereby diminished. The seed may not have sufficient moisture and heat to fully germinate, but it will be kept in a greater state of activity than when in a completely dormant condition. Hence, its vitality is gradually being reduced. Moreover, in certain instances, seeds in bulk stored under moist, warm conditions may " heat " to such an extent that the embryos are actually killed by the high temperature.

5. *Age of Seeds.*—It is well known that seeds gradually lose their vitality as they grow older. The rate at which they lose their vitality depends upon the kind of seed and upon the conditions of storage. Seeds containing oil, such as corn and flax, lose their vitality much quicker than starch-bearing seeds, such as those of legumes. The seeds of legumes are noted for their great longevity. Some have been known to retain their vitality for 150 to 200 years.

The table on page 109 gives the length of time seeds may be expected to retain their vitality under average storage conditions:

Delay in the Germination of Seed.—The seeds of many plants have a rest period. That is, they will germinate better after a period of rest than they will when first mature. This dormancy is more common among wild plants than among domesticated ones. For example, wild oat seeds experience a delay in their germination, seldom germinating the same year in which they are formed. The seeds of a number of weeds will lie in the ground for years in a dormant state. It has been shown that some seeds are still viable after thirty years' burial in the soil. Among such are the seeds of pigweed, black mustard, shepherd's purse, common dock, green foxtail and evening primrose.

Age and Vitality of Seed

Seed	Years	Seed	Years
Alfalfa	6–8	Onions	2–5
Asparagus	5	Parsley	3
Beets	6	Parsnip	2
Cabbage	5	Peas	3
Carrots	4	Pumpkin	5
Corn, field	2	Radish	5
Cucumbers	10	Red Clover	6–8
Kentucky Bluegrass	1–2	Spinach	5
Lettuce	5	Squash	5
Millet	6	Timothy	6
Muskmelon	5	Tomato	4
Turnip	5	Watermelon	5
Wheat, oats, barley, rye and other small grains	1–2	White Clover	2

There is an old saying that one year of seeds means seven years of weeds. A crop of seeds is born; some of them may germinate immediately if the conditions are favorable; others may remain dormant for a year or two, and still others may remain dormant for five or six or more years. In cultivation, the seeds may be buried to such a depth that they do not get enough oxygen to germinate. Consequently, they lie dormant in the soil. Later, perchance, they may be turned to the surface in plowing and brought under conditions favorable to their germination.

The delay in the germination of seeds may be due to several causes. Probably the most common cause is an **impervious seed coat** which prevents or retards the absorption of water. This topic was discussed on page 105. Another cause of dormancy is the **inability of the embryo to break the seed coat.** This is the case in the common pigweed seed. As the seed lies in the ground, freezing and thawing and the action of soil organisms gradually soften the coats and make germination possible. Still another cause of seed dormancy is the **inability of the embryo to germinate until it has gone through a series of changes known**

as "after-ripening." This process may be hastened in some instances by exposure of the seeds to low temperatures.

Hastening the Germination of Seed.—"Hard seeds," whose coats are impervious to water, may be hastened in their germination by scratching the surface. As has been stated on page 105 this is practiced in the cast of such legume seeds as alfalfa

FIG. 52.—Olive seeds clipped in order to hasten their germination. (From Bioletti and Oglesby, in Calif. Agr. Exp. Sta. Bulletin.)

and sweet clover. The delay in the germination of olive seeds, which have a stony covering, may be overcome in part by soaking them in warm water, soaking in alkaline or acid solutions, and clipping the ends (Fig. 52). The last method appears to be the best. Germination of some seeds may be hastened by soaking them before planting in water. For example, asparagus seed soaked a period of three to five days at a temperature of 75° to 85° F. will germinate more quickly than unsoaked seeds. The seeds of beets

and lettuce have their germination hastened by soaking for a period of six hours in water.

Such hard-coated seeds as those of the peach, cherry and walnut are otfen stratified in the early winter and permitted to freeze and thaw in order to break the seed coats. In stratifying seeds, alternate layers of sand and seeds are placed in a box. They are then placed in a well-drained place and allowed to freeze. In mild climates where winter freezes seldom occur, the germination of many seeds is improved by stratifying them in a moist place; the moisture together with the temperature fluctuations are probably responsible.

Relation of Size to Seed to Yield.—Experiments show that, in general, large seeds produce stronger plants and greater yields than small seeds. As a rule, the large seeds contain more stored food than small seeds, and consequently are able to gain advantage due to a more vigorous initial growth. Although small seeds may germinate sooner than the larger, they produce seedlings which are soon surpassed by those from the larger. As an example of the value of large seeds may be cited the case of lettuce. Large lettuce seed of five varieties produced a greater total weight of plants, a larger percentage of heads and of greater uniformity at the time of harvest than small seeds.

Actual Planting Value of Seed.—The quantity of seed to plant per acre varies widely and is determined by a large number of different conditions.

There are two chief factors to consider in judging the commercial quality of seed; first, **purity,** that is, its degree of freedom from sticks, stones, chaff, dirt, weed seed and other seeds; second, **vitality,** that is, its power to germinate readily and produce vigorous sprouts. If both purity and vitality are high, the amount of seed necessary to plant an acre in order to secure a heavy stand will be less than if either the purity or vitality, or both, are low.

The actual planting value of a lot of seed is secured by multiplying the percentage of purity by the percentage of germination of pure seed.

Let us compare the planting value of high-grade and low-

grade alfalfa seed. Alfalfa with a germination of 87 per cent and a purity of 98 per cent may be considered of standard quality. The actual planting value of this seed is (87 × 98) 87.2 per cent. Let us suppose that it takes 10 pounds per acre of this seed at 22 cents per pound. The cost of the seed necessary to plant an acre will be $2.20. Seed with the same germination, but with a purity of 90 per cent will have a planting value of (87 × 90) 78.3 per cent. If 10 pounds of standard quality seed were used per acre, how much of the inferior quality of seed should be used in order to scatter on each square rod the same number of seeds per acre? It will require 10.9 pounds per acre, which, if sold at the same price per pounds as the high quality seed, would give an acre cost of $2.40. Upon the same basis, alfalfa seed with a germination of 60 per cent and a purity of 90 per cent, which is not unusual, will have a planting value of (60 × 90) 54 per cent and will need to be seeded at the rate of 16 pounds per acre, which will give an acre cost of $3.52.

These illustrations are taken to show the great necessity of using the best seed; moreover, the great need of having seed tested before planting in order to have a guide as to how much seed to plant per acre. If the actual planting value is low, more seed will necessarily have to be planted per acre to secure a good stand than when a standard, high quality seed is used.

Character of Impurities in Seed.—We should know more than the purity percentage of seed, however. Two lots of seed may both have a purity of 98 per cent; in the one case the 2 per cent impurities may be largely dodder, a most pernicious and destructive weed; in the other case the 2 per cent impurities may be made up of harmless inert matter such as broken sticks, gravel, etc. A lot of seed with a purity of only 90 per cent may be superior to one with 98 per cent, having the same germinability, if the impurity of the latter is due to noxious weed seeds.

Many of the impurities in commercial seeds may be removed by running the seed through a fanning mill. It is the practice of all reliable seed companies to thoroughly screen their seed to remove weed seeds before it is placed on the market. With the small cereals the fanning mill will remove chaff, wild oats, light and

shriveled seed, smut " balls " and many weed seeds, and thus a much larger percentage of plump, vigorous seeds is secured.

The Necessity of Testing Seed.—Even the most fertile soil, the best seed bed and the most careful cultivation will be useless unless pure, live seeds are planted. Poor seed is often the only cause of crop failure. Poor seed is largely responsible for weedy farms. Weed control will be useless unless more attention is given to the use of pure seed.

Is the seed purchased alive? Will it germinate vigorously? Is the seed purchased filled with dirt, chaff and the seeds of such noxious weeds as wild oats, dodder, bindweed, poverty weed, cheat, sow thistle, wild barley and others? These are questions which give the farmer much concern.

Clearly, there is but one way to find out the true value of a lot of seeds, and that is to give it a thorough test and analysis. It is usually impossible to judge of the quality of seed even by careful examination of handful after handful. The outward appearance of the seed will give one little idea of the vitality of the germ inside. Moreover, there are a number of weed seeds which are often associated with and may easily be mistaken for certain field seeds. For example, the seeds of alfalfa, yellow trefoil, white and yellow sweet clover and dodder have very much the same appearance and may be very easily confused. Testing determines the actual quality of the seed exposed for sale or intended for planting.

Home Methods of Testing Seed.—*The Purity Test.*—A purity test is made (1) to detect adulterants in seed, and (2) to find out the character and amount of weed seeds and inert matter present. The purity is expressed in percentage, and based on weight. Inert matter includes broken seed, chaff and dirt.

Casual inspection of a lot of seed will reveal very few of the weed seeds present, especially when the lot under examination has been milled and the chaff, sticks, and smaller weed seeds removed. A carefully conducted purity test will, because of its thoroughness, result in the detection of all adulterants as well as unmilled weed seeds and inert matter. Take, for example, alfalfa containing a small amount of large-seeded alfalfa dodder. Not

one buyer in ten will detect this undesirable seed because of its close resemblance in size and color to the alfalfa seed.

Samples from home-threshed seed for testing should be taken in such a way as to secure a representative sample. With a knife and with the aid of the tripod lens, the sample is separated into three piles: (*a*) Pure seed, (*b*) weed seeds and other seeds, and (*c*) inert matter. The percentage of purity can be accurately determined when balances are available or roughly estimated if there are no balances to be had.

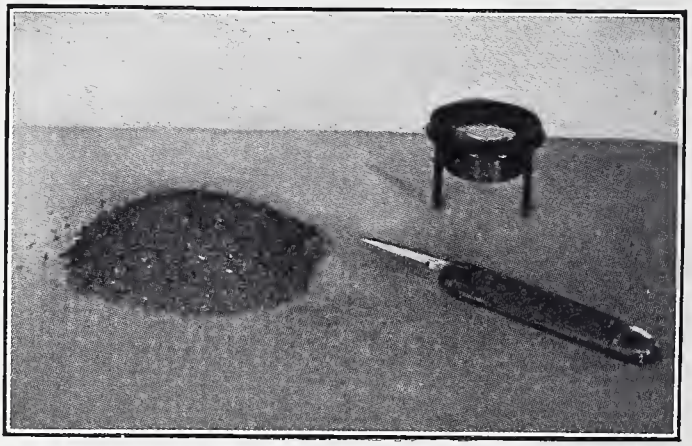

Fig. 53.—Making the purity test. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

The following is an acutal case of a purity analysis of alfalfa seed which will show the steps in the process and the method of computing the percentage of purity.

1. The sample of alfalfa seed was spread out on a piece of white paper or of glass, as shown in Fig. 53.

2. The sample being larger than needed, it was divided and subdivided as shown in Fig. 54, until the desired amount was obtained, approximately $\frac{1}{6}$ oz. (5 grams). In this particular case, the portion separated off for analysis weighed 5.4 grams.

3. With knife and lens, the sample was carefully worked over (Fig. 55) and separated into three piles (*a*) pure seed, (*b*)

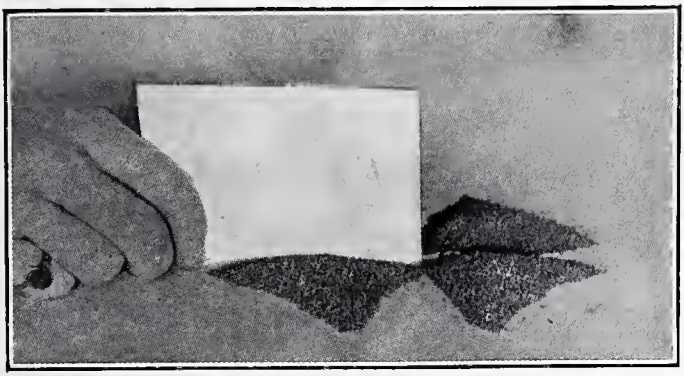

FIG. 54.—Showing the method of dividing the original sample in order to obtain the proper amount for purity analysis. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

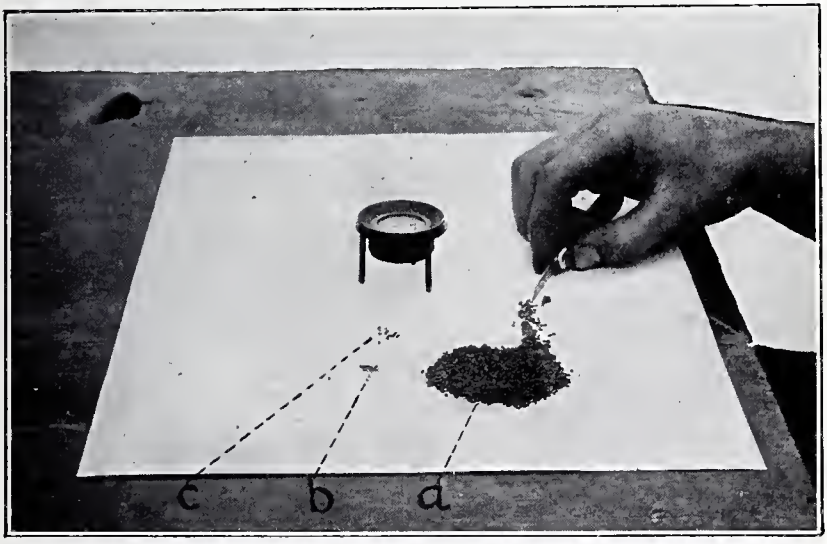

FIG. 55.—The purity test. With a knife and with the aid of a tripod lens, the sample of seed is separated into three piles: (*a*) pure seed, (*b*) weeds and other foreign seeds, and (*c*) inert matter. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

weed seeds, and other foreign seeds, and (3) inert matter (sticks, broken seeds, chaff and dirt).

4. The pure alfalfa seed was placed on the scales and the weight recorded (in this case 5.1 grams).

5. The percentage of pure seed was then computed by dividing the weight of pure seeds, 5.1 grams, by the original weight, 5.4, which gives 94.4 per cent. The remaining 5.9 per cent by weight was composed of weed seeds and other seeds and inert matter, in two piles (*b*) and (*c*). The percentages of (*b*) and (*c*) can be computed likewise. The percentage of inert matter was 1.5 per cent.

Summarizing:

Weight or original sample 5.4 grams.
Weight of pure seed (*a*) 5.1 grams.
Per cent of pure seed 94.1 per cent.
Weight of weed seeds and other seeds (*b*) .24 gram.
Per cent of (*b*) 4.4 per cent.
Weight of inert matter (*c*) .06 gram.
Per cent of (*c*) 1.5 per cent.

6. With tripod lens identify the seeds in pile (*b*). In this case there were seeds as follows:

Lambs quarters	5
Sweet clover	3
Dodder	2
Pigweed	4

The number of any one of these impurities per pound of seed may be computed. For example, there were 2 dodder seeds in 5.4 grams of sample. In one pound there are 454.5 grams. If there were 2 dodder seeds to every 514 grams, in a pound or 454.5 grams, there would be 168 dodder seeds.

7. Determine the character of the inert matter (*c*).

The Germination Test.—There are a number of simple ways of testing seed. The following methods are described here: (1) The dinner plate seed tester, (2) the soil flat or box tester, and (3) the rag-doll tester.

In making the dinner plate seed test, the following seeds should be germinated **between blotters:** Barley, beets, buckwheat, hemp, oats, rye, turnip, wheat, alfalfa, brome grass, clover (crimson), clover (common red), clover (mammoth), Johnson grass, millet, orchard grass, rape, sorghum, sudan grass, cabbages, cauliflower, carrot, cucumber, eggplant, lettuce, melon, onion, parsley, parsnip, pepper, radish, spinach, and tomato.

The following seeds should be germinated **on top of the blotter** and the seeds kept in **dark** by covering them with a dinner plate. Flax, white clover, red top, timothy and celery.

The following seeds should be germinated **on top of blotter,** and the seed kept in the **light** by covering the germinating dish with a plate of glass: Bermuda grass and blue grass.

The following seeds should be germinated **between the folds of cloth:** Bean, corn, peas, cow peas, vetch, pumpkin, salsify, squash, sweet corn, and asparagus.

The Dinner Plate Seed Tester

(*a*) *Seeds to be tested for germination between blotters:*

1. Secure two ordinary dinner plates.

2. Cut a strip of blue or white ordinary blotting paper into a strip about 6 inches by 12 inches, and fold once. (Fig. 56.)

3. Immerse the blotter in water and after draining, place it unfolded on one of the dinner plates.

4. Count out 100 seeds, taking them just as they come, without discrimination and including shriveled as well as plump seeds.

5. Scatter the seeds on one-half of the blotter, so that they do not touch each other.

6. Fold the other half of the blotter over the seeds and cover with another dinner plate, thus making a moist chamber.

7. Place the tester where the temperature will remain at 70° F. It may be necessary to moisten the blotter every day or so. Blotters should always be moist but not saturated.

8. Count the sprouts according to the length of time given in the following table:

SUBSTRATA, TEMPERATURE, AND DURATION OF TESTS

Kind of Seed	Sub-stratum	Temperature	Day for making Germination report	
			Preliminary	Final
** Field Crops*		°F.		
Barley	B	68	3	5
Beans	C	68–86	3	6
Beets..bc	B	68–86	5	10
Buckwheat	B	68–86	3	5
Corn	C	68–86	3	5
Cotton	C	68–86	4	7
Flax	TB	68–86	2	5
Hemp	B	68–86	3	5
Oats	B	68	3	5
Peas	C	68–86	4	8
Rice	B	68–86	3	6
Rye	B	68	3	5
Tobacco	TB	68–86	7	14
Turnips	B	68	3	5
Wheat	B	68	3	5
Grasses, Clovers, Forage Plants				
Alfalfa	B	68	3	5
Bermuda grass....DG	TB	68–95	10	21
Bluegrass.....DG	TB	68–86	14	28
Brome grass	B	68–86	5	10
Clover, alsike	TB	68	3	5
Clover, crimson	B	68	2	4
Clover, mammoth red	B	68	3	5
Clover, medium, red	B	68	3	5
Clover, white	TB	68	3	5
Cow peas	C	68–86	4	10
Crested dog's tail	B	68–86	10	18
Grasses, Clovers, Forest Plants				
Meadow fescue	B	68–86	5	10
Other fescues (Ovina group)	B	68–86	10	21
Meadow foxtail	B	68–86	6	10
Millet	B	68–86	3	5
Johnson-grass	B	68–95	6	10
Orchard grass	B	68–86	6	14
Paspalum	B	68–95	6	14
Rape	B	68	3	5
Redtop	TB	68–86	5	10
Rescue grass....DG	TB	68–95	10	21

* In the case of cereals and timothy grown under such conditions that they are frosted or exposed to cold weather before harvest, the germination tests are made at lower temperatures, 15° to 20° C., and continued for longer periods than for normal seed.

SUBSTRATA, TEMPERATURE, AND DURATION OF TESTS.—*Continued.*

Kind of Seed	Sub-stratum	Temperature	Day for making Germination report	
			Preliminary	Final
		°F.		
Rhodes grass	B	68–86	6	10
Rye grass	B	68–86	6	10
Sorghum	B	68–86	3	5
Sudan grass	B	68–86	3	5
Soy beans	C	68–86	4	8
Sweet vernal grass	B	68–86	6	14
Tall meadow oat grass	B	68–86	6	10
Teosinte	B	86	4	8
Timothy	TB	68–86	5	8
Turnips	B	68	3	5
Velvet grass	B	68–86	6	10
Vetch	C	68–86	4	14
Vegetables				
Asparagus	C	68–86	6	14
Beans	C	68–86	3	6
Beets..bc	B	68–86	4	10
Cabbage	B	68	8	5
Carrots	B	68–86	6	14
Cauliflower	B	68	3	5
Celery	TB	68–86	10	21
Cucumber	B	68–86	3	5
Eggplant	B	68–86	8	14
Kale	B	68	3	5
Lettuce..b	B	68	2	4
Muskmelon	B	68–86	3	5
Okra	C	68–86	4	14
Onions	B	68–86	4	7
Parsley	B	68–86	14	28
Parsnip	B	68–86	6	21
Peas	C	68–86	3	6
Pepper	B	68–86	4	10
Pumpkin	C	68–86	3	6
Radishes	B	68	3	6
Salsify	C	68–86	5	10
Spinach	B	68	5	10
Squash	C	68–86	3	6
Sweet corn	C	68–86	3	5
Tomato	B	68–86	4	10
Turnip	B	86	3	5
Watermelon	B	68–86	4	6

NOTE.—B—between blotting paper; TB—top of blotting paper; DG—daylight germinator; C—between folds of cloth; b—soak six hours in water at room temperature before testing for germination; c—the germination of beet seed is confined to determining the percentage of balls which give sprouts.

The question is sometimes asked: "Why make both a preliminary and a final count of the sprouts?" This is to show the energy of germination or the power of the seed to respond quickly to growth conditions. Two lots of seed may show about the same final percentage of live seeds but one lot be more vigorous than another, and this relatively greater vigor is usually indicated in the preliminary count. For example, two lots of wheat (a) and (b) under similar germinating conditions, at the

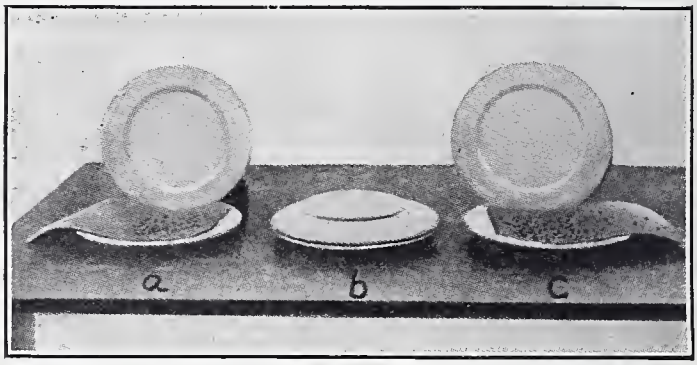

FIG. 56.—The dinner plate seed tester. (*a*) One hundred seeds are scattered on one half of the blotter. The other half of the blotter is folded over the seeds. (*b*) Cover with another dinner plate, thus making a moist chamber. (*c*) The seeds have germinated, and the sprouts are ready to be counted. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

end of three days showed 80 and 92 per cent sprouts respectively; while at the end of 5 days (a) showed 93 per cent and (b) 95 per cent, very nearly the same. But the sprouts of (b) were more vigorous than those of (a), and this fact was readily shown in the difference between the preliminary counts of germination. Preliminary counts are also valuable in that they remove sprouted seeds and prevent crowding in the later stages of germination.

(b) *Seeds to be tested for germination on top of blotters, and in dark:* Proceed as in the preceding case, but do not cover the seeds with a fold of blotter. Small seeds of the type given in the list on page 117 germinate best on top of the blotter.

(c) *Seeds to be tested for germination on top of blotters and in the light:* Proceed as in the preceding case, placing seeds on top of blotter, but cover the dinner plate with a plate of glass so that the germinating seeds will be exposed to the light (Fig. 57).

(d) *Seeds to be tested for germination between folds of cloth:*

1. Secure two ordinary dinner plates.

2. Cut a strip of cotton flannel cloth or Canton flannel 8 inches by 32 inches and fold cross-wise twice.

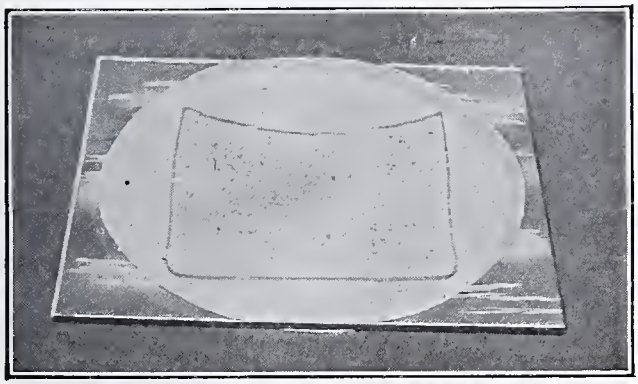

FIG. 57.—The seeds of bluegrass and Bermuda grass should be germinated on top of a blotter and kept in the light; cover the germinating dish with a plate of glass. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

3. Immerse the flannel in water and after wringing out, place it, unfolded so as to leave two thicknesses of cloth on top and two thicknesses of cloth on the bottom of the seeds.

4. Count out 100 seeds taking them just as they come, without discrimination and including shriveled as well as plump seeds.

5. Scatter the seeds on one-half of the cloth, so that they do not touch each other.

6. Fold the other half of the cloth over the seeds and cover with another dinner plate, thus making a moist chamber.

7. Place the tester where the temperature will remain close to 70° F. It may be necessary to moisten the cloth every day or so. Keep the cloth moist but not saturated.

8. Count the sprouts according to the length of time given in the preceding table.

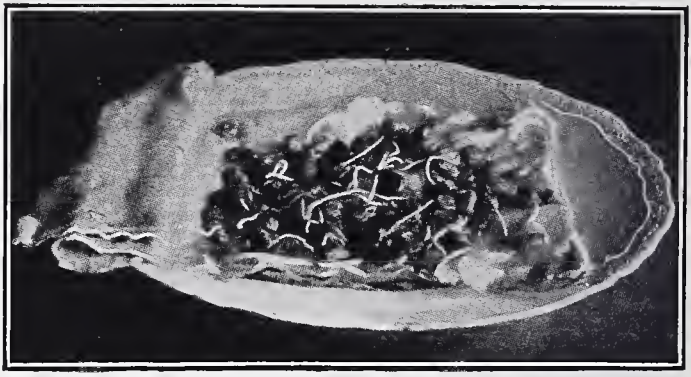

FIG. 58.—Germinating seeds between the folds of Canton flannel. Use two dinner plates, one inverted over the other. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

The Soil Flat or Box Tester

This is used by many in making individual ear-tests of corn (Fig. 59).

1. Fill a small shallow box or soil flat with soil or sawdust to about $\frac{3}{4}$ its depth.
2. Then thoroughly moisten the soil or sawdust.
3. Cut a square strip of Canton flannel to fit the box top.
4. With pencil, mark off the flannel (smooth side) into 2-inch squares.
5. Number each square, 1, 2, 3, etc., to correspond with the numbers on the ears to be tested.
6. Place the flannel in the box and push down gently until in contact with the sawdust or soil.
7. Moisten the flannel thoroughly.
8. Select 10 kernels from different parts of each ear and place these on the corresponding square, that is, kernels from ear No. 1 on square No. 1, etc.
9. Cover the seeds with a second layer of Canton flannel, and moisten well.

FIG. 59.—The soil flat or box tester, used in making individual ear tests of corn. (*a*) Number the squares on the cloth and ears to correspond; (*b*) place the kernels from individual ears on the squares; (*c*) cover the seeds with a second layer of Canton flannel, moisten, and cover with moist soil or sand; (*d*) at proper time, remove the top cloth carefully, count and record the sprouts. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

10. A final layer of moist soil or sand over the top layer of flannel will hold the moisture for a greater length of time and will demand less attention than the single layer of moist cloth.

11. Count the sprouts at periods stated in the table.

12. In removing the top cloth for the purpose of counting sprouts, exercise care or confusion will result, as the sprouts often penetrate both the cloth and soil. Roll back the cloth slowly and carefully.

Rag Doll Tester

1. In making the rag-doll tester, select white muslin, Canton flannel or other white material that is sufficiently porous to hold moisture (Fig. 60).

2. Cut in strips 14 to 16 inches wide and as long as desired, preferably 4 to 6 feet, depending upon the number of ears to be tested.

3. Draw a line down the center of the strip.

4. Leave a strip 3 or 4 inches wide at the ends.

5. Mark the strip cross-wise at 3- or 4-inch intervals, making a number of sections either 3×7, 3×8, or 4×8 inches.

6. Number the sections 1, 2, 3, etc., to correspond with the numbers on the ears to be tested.

7. Moisten the cloth thoroughly before putting the kernels upon it.

8. Select 10 kernels from different parts of ear No. 1, and place in section No. 1. Repeat the process with 2, 3, etc.

9. Place kernels about 2 inches from the dividing line and 1 inch from the cross lines.

10. Fold each side of the cloth over until the edges meet in the middle.

11. Press the cloth down firmly over the kernels to prevent kernels from rolling or sliding from one section to another.

12. Using either a corn cob or cylindrical object, roll up the cloth, and fasten with a cord, rubber, or pins.

13. Immerse the rag doll in lukewarm water and allow to soak one or two hours.

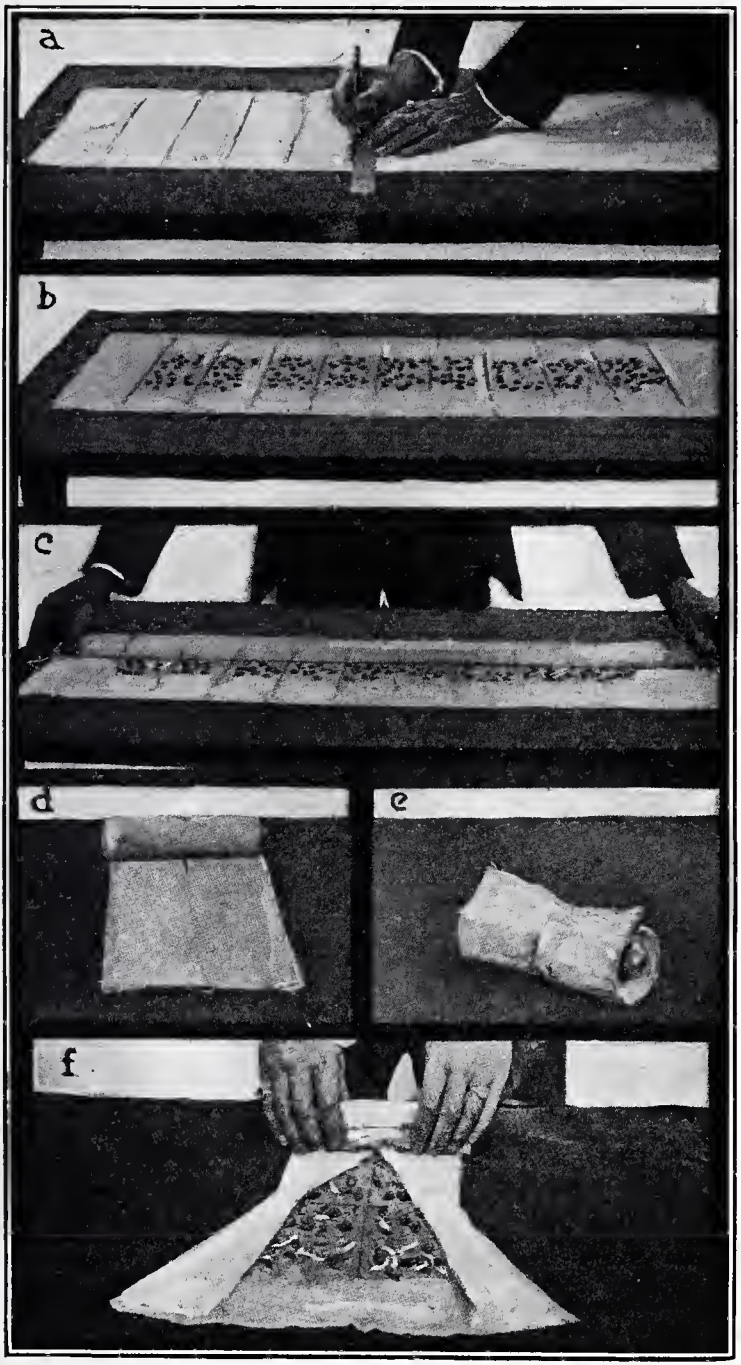

FIG. 60.—The rag doll tester, used in making individual ear tests of corn. (From Robbins and Egginton, in Colo. Agr. College Extension Bulletin.)

14. Remove the doll and allow it to drain.

15. Keep in a warm place between 80°–90° F. during the day and 50°–60° at night.

16. Do not allow the doll to dry out. Wrap a wet cloth around it if necessary.

17. Count the sprouts at the end of five days.

18. Before using the doll a second time, it should be sterilized in boiling water.

State Seed Laws.—There are now 26 states with seed laws, nearly all of which specify that seed which is sold, offered or exposed for sale shall be labeled. The requirements on the label vary somewhat with the different states, but in most of them the label must contain the following:

1. Commonly accepted name of the seed.
2. Percentage of germination.
3. Date of germination.
4. Percentage of purity.
5. Name and number of noxious weed seeds per pound.
6. Name and address of seedsmen.

The enforcement of these seed laws has prevented the sale and distribution of much inferior seed; it has caused the seedsmen to use more care in cleaning seed; it has prevented adulteration to a large extent; it has taught farmers everywhere the value of good seed.

Seed Importation Act.—There is a national seed importation act which regulates the importation of all seeds into the United States.

Seeds as Carriers of Disease.—Seeds may carry diseases. The grower then must not forget that in addition to **pure seed,** and **viable seed,** there is a third essential, **disease-free seed.**

Some of the diseases most dreaded in farm crops are among those carried over on agricultural seeds. Together with the handling of disease free seed comes the problem of clean soil. The latter is greatly influenced by the quality of seed sown. It has been shown, at least for some sections of the United States, that the use of bad seed and infested soil associated with constant cropping brings about soil-sickness for such crops as wheat, rye

and barley, and perhaps many others. There is no doubt that poor yields in many cases are entirely the result of noxious diseases introduced to the soil and crop by means of infested seed. Parasitic diseases introduced into a soil are apt to persist year after year and do considerable damage, the amount of which depends upon the kind of soil and atmospheric conditions. In contact with the seed, these diseases are readily distributed from crop to crop and from season to season. In fact, they may be so well protected within the shallow parts of the seed or within the seed coats themselves as to effect distribution over long distances as from Europe to America, or vice versa. Disease germs thus concealed upon the seed may escape the most careful observer, so that the proof of bad seed appears first in the crop. Poor yields should arouse suspicion regarding the health of the seed; missing plants, shriveled grain, unusual yellowing of leaves, and dwarfing, all may easily be the result of fungi which gained foothold by the route of unclean seed.

Tests have shown that there are at least four different kinds of fungi which may be found inside the grains of corn. These fungi are usually within the seed coats at the tip of the kernel, and probably grow into the kernel when the ear is maturing. The fungi mentioned cause root rots, a dry rot of the ears, and a pink rot of the kernels. When kernels carrying one or more of these diseases are planted, the resulting plants are usually less vigorous than those from healthy kernels. Germination tests should be made to detect and reject seed ears injured by fungi. Sometimes an apparently healthy ear carries disease. The only way of culling out the diseased ears is by making a germination test.

Advisability of Disinfecting Diseased Seed.—There is hardly a group of plant diseases known which can be more readily and completely controlled than those carried on the outside of seeds. Considering the cost of treatment, which seldom exceeds two cents per bushel, the farmer can ill-afford to use anything but clean seed. Whenever any noticeable number of diseased plants is seen in a field, there always occurs a material loss of the crop, hence prompt means of eradication should always be taken, depending upon the disease present. Not all diseases can be

controlled by treatment of the seed, as for instance, wheat rust, mildews or blights, or even corn smut, but on the other hand, many cereal smuts, certain anthracnoses and various vegetable diseases are best controlled by seed disinfection.

It is not always an easy matter to determine whether or not fungi are attached to seeds wanted for seeding purposes, but it is very unwise to use seed known to have come from diseased fields, even in small amounts.

Seed treatment is very simple and can be performed with a very small outlay of materials and a minimum of trouble. The principle of most seed treatment is to kill fungous spores lodged on the surface of the seed by the application of a disinfectant solution. The solution must be strong enough to destroy the spores, but cause no injury to the grain. For this purpose formalin and corrosive sublimate are most in use. Formalin is a solution of formaldehyde gas in water. When purchased for seed treatment, it should possess 40 per cent concentration. All druggists have this strength in stock. Corrosive sublimate is a severe poison and when employed for seed disinfection, the seed should not be fed to live-stock. It is diluted in the proportion of one part to 1000 parts of water. Corrosive sublimate is sold in the form of a powder and readily dissolves in lukewarm water. Solutions of copper sulphate, and copper carbonate dust are also used in the treatment of seeds.

How Seeds are Carried.—The chief agencies in the dispersal of seeds are, **wind, water,** and **animals,** including man. Some seeds have special adaptations favoring dispersal by wind (Fig. 61). Here may be mentioned the winged seeds of maple, elm and pine; the seeds of cotton, milkweed, and willow, which have long silky hairs, and the seeds of lettuce and dandelion, which have parachute-like tufts of hairs.

Some seeds have structures which enable them to be carried readily by water. For example, the seeds of the sedge are surrounded by a membranous envelope containing air.

A number of different kinds of seeds have structures which favor their spread by animals (Fig. 61). For example, sand-bur seeds have spines; and those of Spanish needles and cockle-bur

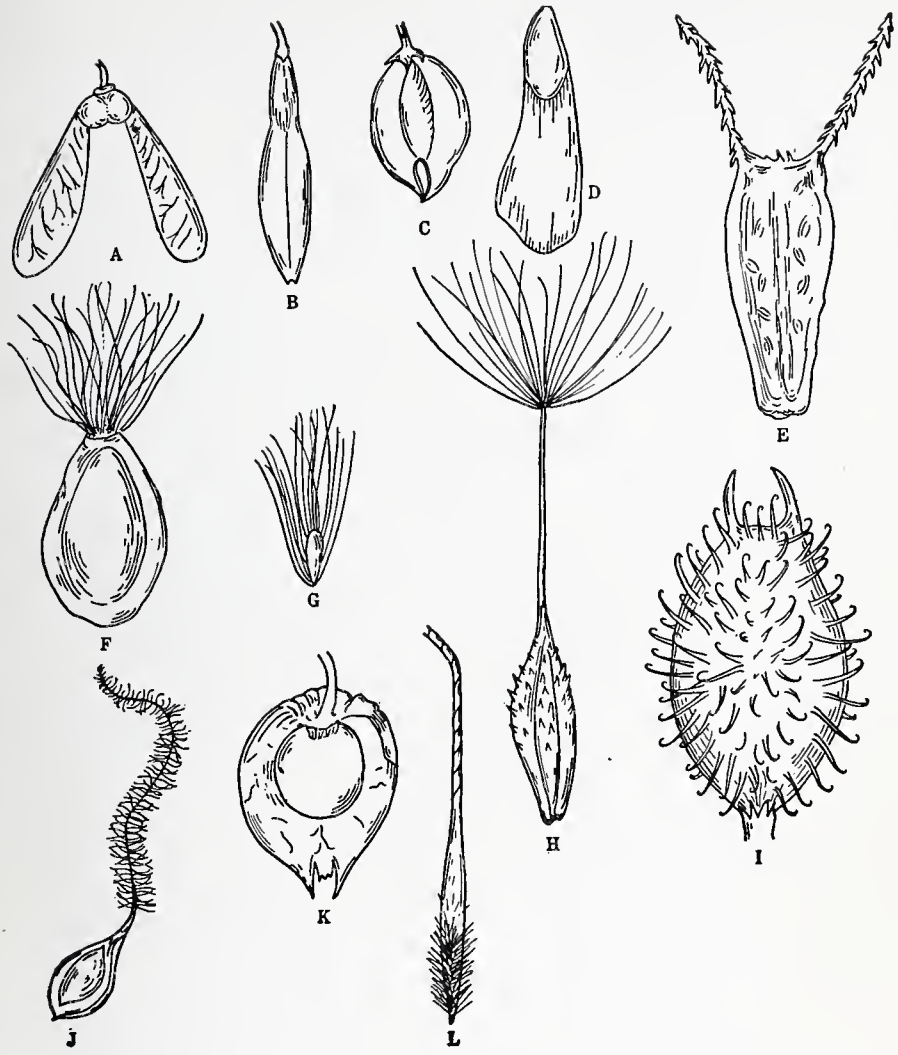

FIG. 61.—Various fruits and seeds showing devices which facilitate their spread. *A*, winged fruit of maple; *B*, winged fruit of ash; *C*, winged fruit of elm; *D*, winged seed of pine; *E*, barbed seed of Spanish needles; *F*, milkweed seed with tuft of hair; *G*, hairy seed of cottonwood; *H*, dandelion fruit with parachute-like tuft of hairs; *I*, hooked fruit of cocklebur; *J*, fruit of clematis with long plume-like style; *K*, fruit of ground cherry with membranous envelope; *L*, bearded fruit of porcupine grass. (Redrawn from Holman and Robbins, in *A Textbook of General Botany.*)

have hooks or barbs, which enable them to cling to the hair of animals or to the clothing of man. Many seeds are carried long distances by birds which have eaten the fruit containing them.

Man is a most important agent in distributing seeds. Many European plants are now at home in this country, their seeds have been brought here as impurities in shipments of commercial seeds. Weed seeds are also carried in screenings, in baled hay, in the packing about trees, in feed-stuffs, and in manure. The " puncture vine " has barbed seeds which are readily carried in automobile tires.

CHAPTER XIII

THE PROPAGATION OF PLANTS

The propagation or multiplication of plants is artificially carried on in many ways, depending upon the kind of plant and the object in view.

Two Distinct Methods of Propagation.—Among the seed plants, there are two distinct methods of propagation: (1) by the use of seeds, and (2) by the use of some vegetative organ, such as stem, or root, or leaf.

We have learned that in the seed there is an embryo, or young plant, and that it is formed as a result of the process of fertilization. The embryo of the seed is a result of the union of two sex elements. One of these elements, the pollen grain, may or may not have come from the plant which bears the seed; if it did not, then the embryo in the seed has characters of two parents. This means that when a plant is cross-fertilized, the resulting seeds will produce plants in many particulars **unlike** the parent which bears them. **Propagation by seeds is a sexual method.**

On the other hand, when a plant is propagated by means of stems or roots or leaves, we may be certain that the parts used will produce plants closely resembling those from which they were taken. **This method of propagation is vegetative.**

Let us cite an example which further distinguishes between the methods of propagation by seeds and by vegetative organs. The pollen of strawberries is carried chiefly by bees; hence there are great chances that the ovules of any particular flower will be fertilized by pollen from another plant. If they are so fertilized, the embryo which results will possess characters of two parents. This accounts for the fact that strawberries seldom come true to type when grown from seed; that is, are like the parent plant

from which the seed was taken. If we wish to propagate a desirable variety of strawberry and keep it " true," we use the " runners," or vegetative parts (Fig. 62). Runners are merely " chips off the old block."

Propagation by the use of vegetative organs is practiced in cases where the plants do not come true from seed. This is the case with hydrids and many horticultural varieties. Also, there are a number of plants such as sugar cane, banana, sweet potatoes,

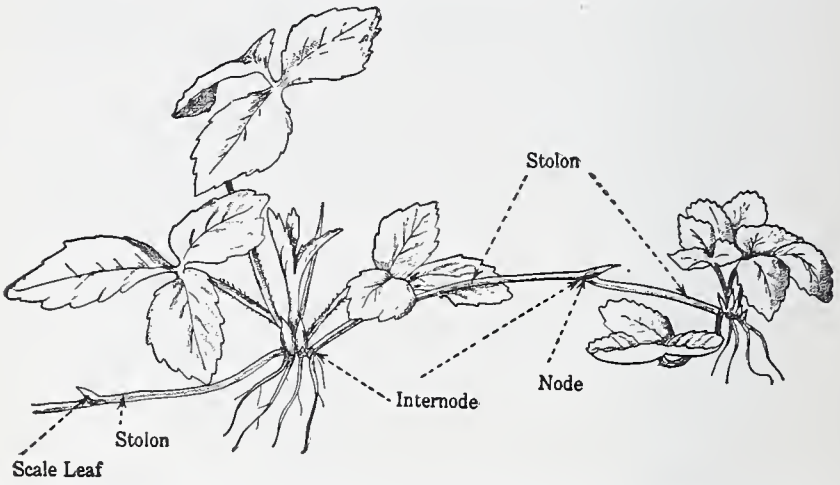

FIG. 62.—A strawberry plant showing propagation by means of "runners" or stolons. (From Holman and Robbins, in *A Textbook of General Botany.*)

and Irish potatoes which seldom produce seed, and of course, must be propagated vegetatively.

In propagating plants by vegetative means use is made of **stems,** of **roots,** and of **leaves.** Many more plants can be vegetatively propagated by means of stems, than by roots, or leaves. A stem structure usually may be readily distinguished from a root, as follows: The stem is divided into definite joints and the buds, hence, the branches, arise in regular order; the buds occur in the axils of the leaves; roots, on the other hand, do not have definite joints, and usually bear no buds or leaves. A relatively few plants can be propagated by means of their roots. Among such

may be mentioned the sweet potato, dahlia, raspberry, and certain blackberries. Rarely, the leaf may be employed as a propagating organ. A striking example is seen in the case of begonia or Bryophyllum (Fig. 63).

The methods of vegetative propagation are many. The principal ones are briefly discussed in the few following paragraphs.

Propagation by Separation.—In this process of propagation use is made of such vegetative parts of the plants as become detached **naturally.** These include such structures as bulbs, bulblets, bulbels, corms and tubers. Each of these possesses

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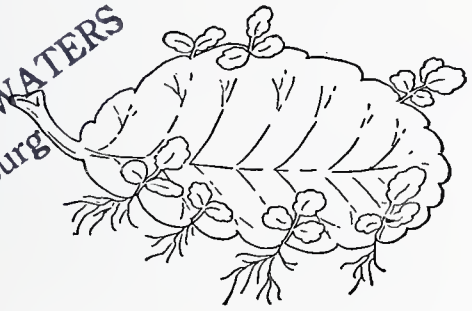

FIG. 63.—Leaf of *Bryophyllum* which has been laid flat on moist sand, showing small plants which have developed at notches on the margin. These young plants may be separated from the parent leaf, and lead an independent existence.

one or more buds, which are capable, under proper conditions, of growth.

Bulb.—A splendid example of the bulb is the onion. Examination of the mature bulb of the common onion shows it to be made up of the much-thickened bases of leaves, attached to a small, cone-shaped stem. These leaves are quite rich in food material. The bulb possesses a terminal bud and occasionally lateral buds in the axils of the leaves.

Bulbel.—Often a number of small bulbs will develop about a large mother bulb. These are called bulbels. For example, in the white lily (*Lilium candidum*) a group of bulbels is formed at the top of the mother bulb, and each produces a number of

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roots. These bulbels may be separated from the mother bulb, and each used to propagate a new plant.

Bulblet.—These are small bulbs which are developed above ground, usually in the axils of leaves or in the flower group. They do not differ essentially from bulbels except in their position on the plant. In the tiger lily (*Lilium tigrinum*) small bulbs occur in the axils of the leaves, and may be removed from the

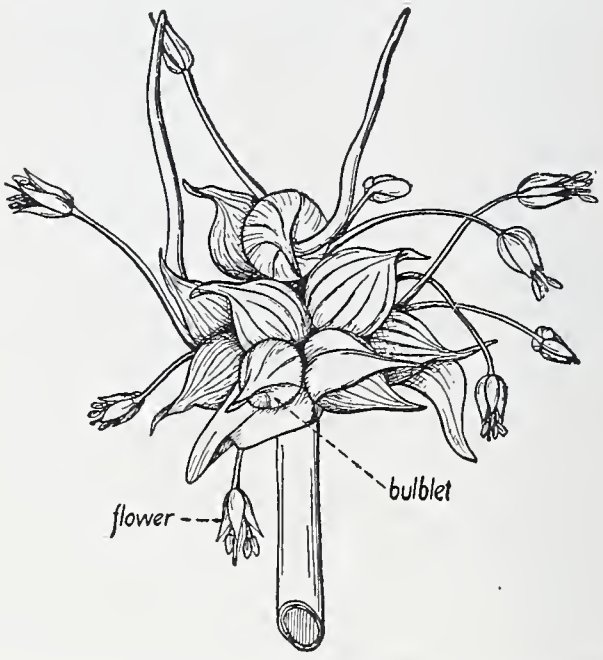

FIG. 64.—Top onions. Bulblets are produced in the flower cluster. (From Robbins, in *Botany of Crop Plants.*)

parent plant and used for the purpose of propagation. In "top," "tree" or Egyptian onions, clusters of bulblets (Fig. 64) are developed at the top of the flower-bearing stalk. They will grow while still attached to the stem, but, of course, are detached for the purposes of propagation.

Corm.—This type of stem is well exemplified in the crocus and gladiolus (Fig. 65). It is a short, solid underground stem, that differs from the bulb in the absence of scale leaves. The corm is usually flattened from top to bottom, and bears a cluster

of thick fibrous roots at the lower side, and a tuft of leaves on the upper side. A number of small corms, called cormels, may develop on the mother corm. Both the large corm and the cormels may be used in propagation.

Tuber.—The best example of the tuber is the common Irish potato (Fig. 66). It is a simple enlargement of the tip of a slender

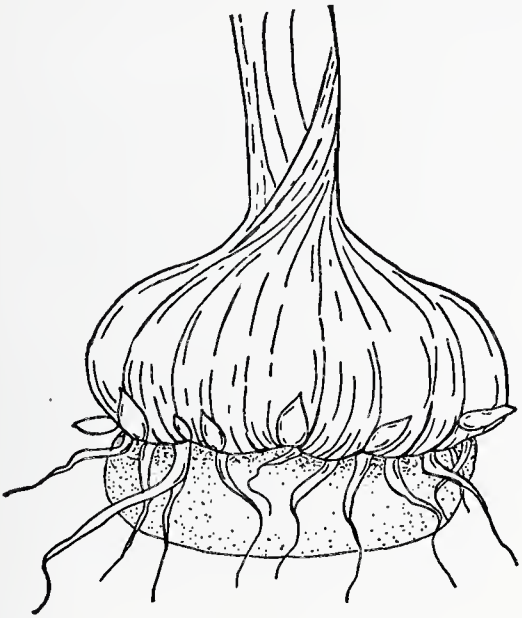

FIG. 65.—Corm of gladiolus. Observe the old corm from which the new one has arisen, and number of cormels at the base of the latter.

underground stem. The buds of the potato tuber usually occur in groups, each group being called an "eye." The potato plant may be propagated by planting the whole tuber, or by cutting it into pieces, each piece having one or more "eyes."

Propagation by Division.—In this method of propagation, living vegetative organs are **artificially** broken or cut into sections, or pieces, and these placed under conditions suitable for growth. For example, as cited previously, the tuber may be divided into a number of pieces, each having one or more eyes (buds), and these employed to propagate the plant. Plants such as canna,

iris, asparagus (Fig. 67), rhubarb, and ferns which produce horizontal underground stems (rhizomes or rootstocks), may be readily propagated by dividing these into a number of sections, each of which bears several buds. Most of our perennial herbs may be

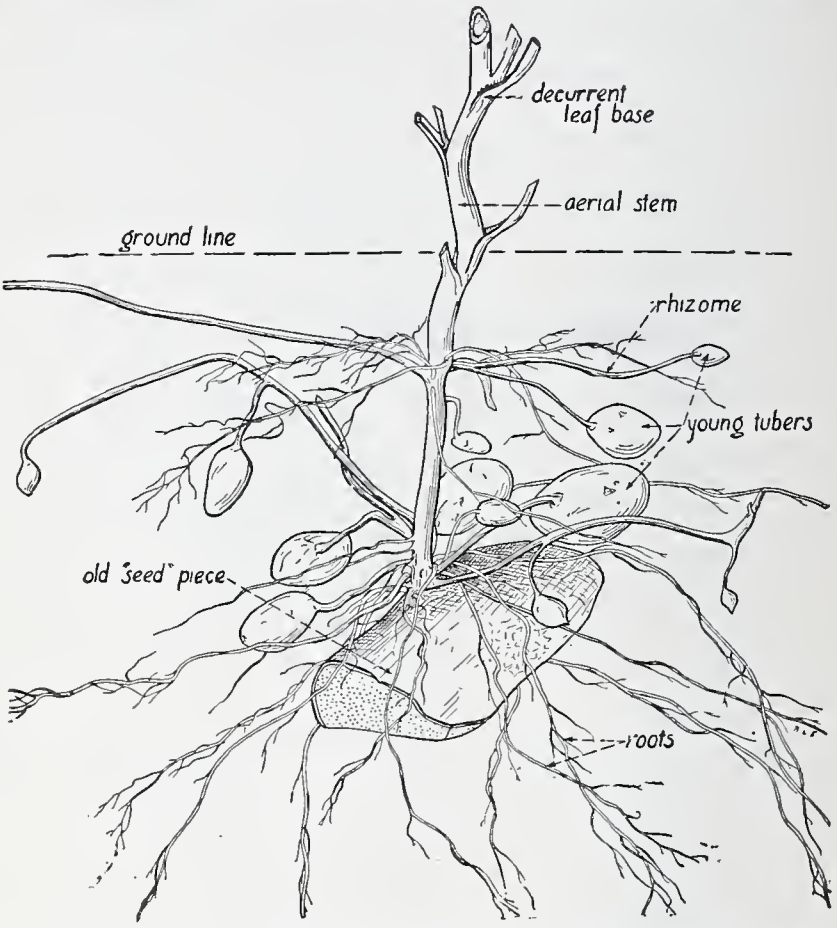

FIG. 66.—Portion of a sprouting potato tuber. The young tubers are the swollen tips of slender underground stems (rhizomes). (From Robbins, in *Botany of Crop Plants.*)

propagated by division of the "crown." The name "crown" usually applies to that part of a perennial plant which is just below or at the ground surface, and which is essentially a clump of shortened stems bearing buds, and roots.

Propagation by Cuttings.—In this method, some vegetative part of the plant is detached and placed under conditions favorable for growth. Cuttings may be made from stem, root, or leaf. Of course, the cutting must contain living tissue, and have a certain amount of stored food for growth, and be capable of developing growing points. The growth of the missing organs from a cutting is a case of **regeneration.** It is believed that any vegetative part

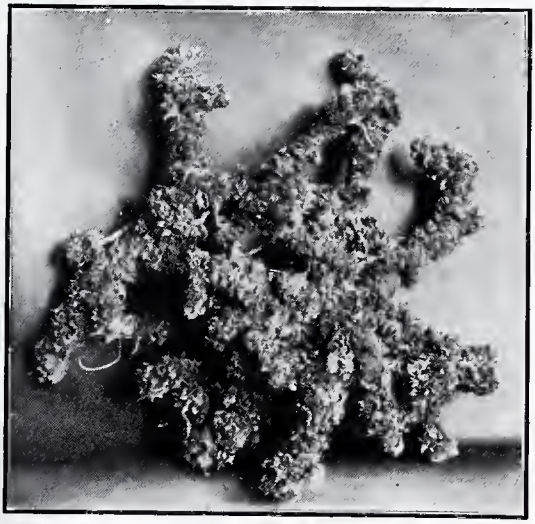

FIG. 67.—So-called "crown" of asparagus, six years old. This is an underground stem (rootstock or rhizome) with many branches.

of a plant (stem for example), which possesses active, growing cells has the power of regenerating the missing organs (roots, leaves, and flowers), if placed under proper environmental conditions. Failures are probably due to our inability to create satisfactory growth conditions. We have learned by experience that some plants can be propagated easily by stem cuttings, other by root cuttings, and relatively a few by leaf cuttings. We can not always tell by observation of the plant whether or not these organs can be used to propagate its kind. We are still unable to offer a satisfactory explanation why root cuttings of such plants as the blackberry and red raspberry will readily produce buds,

whereas those of many other plants under the same conditions lack this power.

Cuttings should be placed under conditions favorable for the rapid healing of the cut surface. When a stem is cut in such a way as to involve the growing layer or cambium, the cambium is stimulated to active growth and forms a mass of large thin-walled cells known as **callus** (Figs. 68 and 69). It is generally believed

FIG. 68.—Callus formation in blackberry cuttings. (From Division of Pomology, College of Agriculture, University of California.)

that callus formation must precede the development of roots, although it is known that roots do not arise directly from callus tissue. A new cambium arises by differentiation of inner callus cells, and as a rule it is from this cambium that the growing points of roots and stems originate. However, best results are usually obtained from callused cuttings. At any rate, the conditions which favor the development of callus also favor root formation.

Stem Cuttings.—These may be made from:

1. *Mature or dormant growth,* that is, from hard or ripened wood, or from

2. *Immature growth,* that is, from soft wood or from herbaceous stems which are vegetatively active.

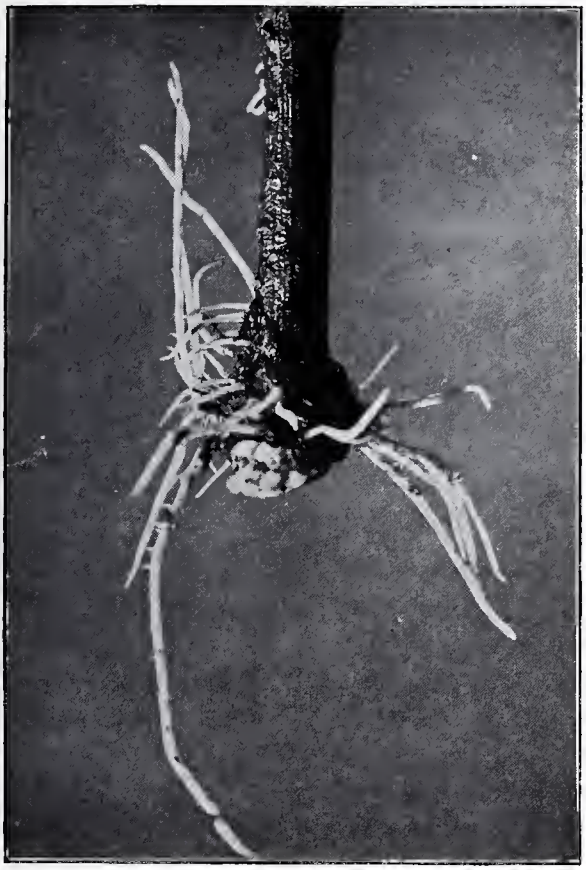

FIG. 69.—Showing the independence of root and callus formation. (From Bioletti, in Calif. Agr. Exp. Sta. Bulletin.)

As a rule, in cuttings of mature growth (Fig. 70), wood of one season's growth is employed, although sometimes wood two or more years old is used. Cuttings are usually made from 6 to 10 inches long, although they may be longer or shorter. Each cutting should possess at least one, but preferably two or three

buds. It is advisable to cut the lower end just below a bud. The cuttings are usually made in the fall or early winter. They are then stored in a place that is warm and moist enough to allow callus formation and some root growth but not warm enough to permit bud growth. Root growth will proceed at tempera-

Fig. 70.—Root and stem cuttings. From left to right: root cutting, hard-wood cutting, soft-wood cutting, and soft-wood cutting showing proper and improper age of stem from which cutting is to be made; the stem should snap in two when bent, as shown at the left, rather than crush, as shown at the right. (Figure at right redrawn from Kains, in *Plant Propagation.*)

tures too low for bud growth. It is often the practice to bury the cuttings, in bundles, with the uppermost buds downward. Thus the cut end of each stem is near the soil surface, which being warmed first in the spring, stimulates the development of roots. Cuttings should be set out in the spring before the buds open.

It is possible to propagate most plants from immature growth, although greater care is often required to get them to root than

is necessary in the case of hard wood cuttings. Stems should be used that are neither too hard nor too soft, but break with a snap when bent. Such plants as begonias, coleus, geraniums, and chrysanthemums are propagated by green cuttings, or so-called "slips." They are usually grown in hotbeds or greenhouses. It must be kept in mind in the growing of cuttings that the tissues above ground are subject to the loss of water for a period before there is root development and sufficient water absorption. This makes it necessary that the water-losing surface be reduced by removing most of the leaves, and that the cuttings be protected in some way from drying out. The small leaf surface that is left on the plant manufactures food that is used in the formation of roots.

Root Cuttings.—Many plants can be propagated by means of root cuttings (Fig. 70). The sections of the plants used in this case do not possess buds. Buds developed during growth of the cutting. Root cuttings are planted shallowly, about one-half to three-fourths inch deep. Among plants that can be propagated by root cuttings may be mentioned the blackberry, red raspberry, horse radish, willows, poplars, osage orange, plums, cherries and juneberry. Generally those plants which have a tendency to produce suckers from the roots can be propagated readily by means of root cuttings.

Leaf Cuttings.—A number of plants, chiefly ones with thick, fleshy leaves, can be propagated by means of leaf cuttings. Among such are begonias, bryophyllum (Fig. 63), gesnera, and gloxinias. The leaves may be cut into a number of pieces, each including a part of a main vein. Under proper growth conditions, the ends of the veins callus, and roots and buds are developed. In the case of bryophyllum, the whole leaf may be used, without cutting the veins; when this is placed in contact with moist sand, roots and buds are formed at the notches.

Propagation by Layering.—This is a method by which the plant is propagated on its own roots. In consists in bending over a portion of a branch (Fig. 71), and covering it with soil to keep it moist. Roots develop at the nodes that are covered, and buds at these rooted nodes develop. The section of the stem thus rooted may be severed from the parent plant and lead an inde-

pendent life. In many plants, rooting of the buried stem may be hastened by injuring it. This appears to limit the movement of food and brings about its accumulation above the point of cutting from which roots develop. Plants which root readily at the nodes, when their branches come in contact with moist earth, are easily propagated by layering. As contrasted with cuttings, the layer is attached to the parent plant, and thus derives water and food from it until it becomes established. Thus it is a more certain mode of propagation than that of cuttings. Among plants which are commonly layered are wisterias, honeysuckles, grape, passiflora, raspberry and hydrangea.

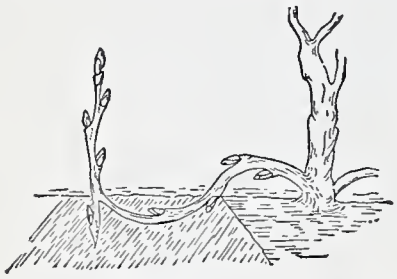

Fig. 71.—Propagation by layering. A branch is bent down and partly buried. It is here shown wounded, which seems to hasten root development. (Redrawn from Kains, in *Plant Propagation.*)

Propagation by Suckers.—In the strict sense a sucker is a stem arising from an adventitious bud which develops on a root. The term is sometimes wrongly extended to include branch stems from the base of the plant. Among plants which develop suckers may be named the silver-leaf poplar, black locust, blackberry, red raspberry, and plum. Propagation by suckers involves cutting off a portion of the root which bears the sucker, and transplanting.

Propagation by Stolons or Runners.—A stolon or runner is a stem that grows more or less horizontally along the surface of the ground. The best common example is the strawberry (Fig. 62). This plant naturally propagates itself by means of runners. A runner is sent out from the parent plant, and produces both roots and new shoots at the tip, after which the runner may die, thus severing the daughter plant from the parent. The young plants which form at the rooting nodes of the runner may be cut off and set out. Stolons form roots naturally, but rooting may be hastened by covering them with soil. It will be readily observe that the layer is in reality an artificial stolon.

Propagation by Grafting.—This is a very old horticultural practice, and is in common use in propagating fruit trees. The fruit grower, in order that he may be certain as to the variety he will have, propagates them vegetatively, one of the chief ways being by grafting. The operation may also be carried on in order to change the size of the tree. For example, when pears are grafted on the more slowly growing roots of the quince, the

FIG. 72.—Grafting tools. (From Division of Pomology, College of Agriculture, University of California.)

stock in this case retards the growth of the pear, and dwarfing results. Another object of grafting is to grow desirable varieties on disease resistant roots, or on roots which will adapt the plant to various soil conditions. For example, the northern California black walnut is resistant to a soil fungus (mushroom) known as *Armillaria*, whereas the English walnut is not so resistant to the organism; this is one reason for the practice of grafting the English walnut on black walnut. The Northern Spy variety of apple is resistant to the woolly aphis which attacks the roots;

this variety is used as a stock upon which to graft less resistant kinds. The common peach is sometimes grafted on Davidiana root, because of the latter's resistance to alkali. The common pear varieties are grafted on Japanese pear roots to better adapt them to light, well-drained soils, or on French pear roots to better adapt them to heavy, poorly drained soils.

Three kinds of grafting are recognized: Scion-grafting, bud-grafting, and approach-grafting. In **scion-grafting** (Fig. 73),

FIG. 73.—Cleft grafting. At right, two views of the scion, and at left, the scions in position in the cleft of the stock.

a stem called the **scion,** containing several buds, is attached to another rooted stem, or root, called the **stock,** in such a way as to bring the growing layers (cambiums) of each together. After a time there is a union of the stock and scion. In **budding** (Fig. 75), the scion used is a single bud together with a small strip of bark. This is attached to the cut surface of the stock so as to bring the growing layers of stock and scion together. **Approach grafting** (Fig. 79), also sometimes known as **inarching,** consists in uniting

two plants while they are still growing on their own roots. It is obvious that this is only possible between plants which are standing close together, or between different parts of the same plant. As a rule, approach grafting is executed by removing a piece of the bark, down to the cambium, of the two stems to be united, and binding these two cut surfaces together. After the two have grown together, the scion is cut off below the union, and the

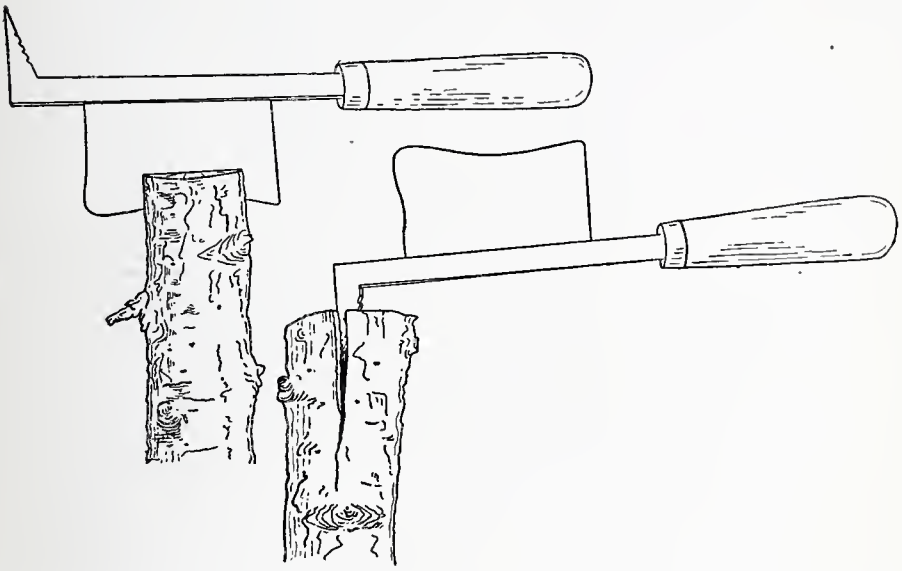

Fig. 74.—Cleft grafting. Left, making cleft; right, cleft being held open for inserting scion. (From photograph by Division of Pomology, College of Agriculture, University of California.)

stock above the union. Care should be taken to sever the scions gradually in order that growth will not be retarded.

It is well known from experience that certain plants can be grafted upon one another, whereas others are united with difficulty. For example, peach can be grafted on the plum, but it can not be grafted on the apple. As a general rule, the more closely two plants are related botanically, the better are the chances of a union by grafting. Plants belonging to different families can not be grafted. For example, it is impossible to graft the peach, which is a member of the rose family, upon the walnut, a member of the

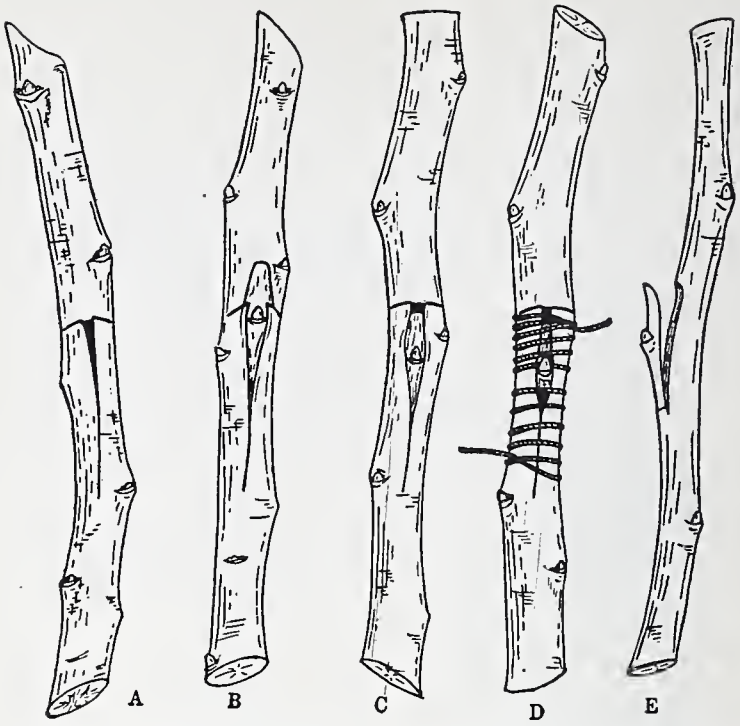

FIG. 75.—Steps in shield budding. *A*, the T-cut in the stock; *B*, inserting bud; *C*, bud in place; *D*, bud tied; *E*, bud stick, showing bud ready for inserting in stock.

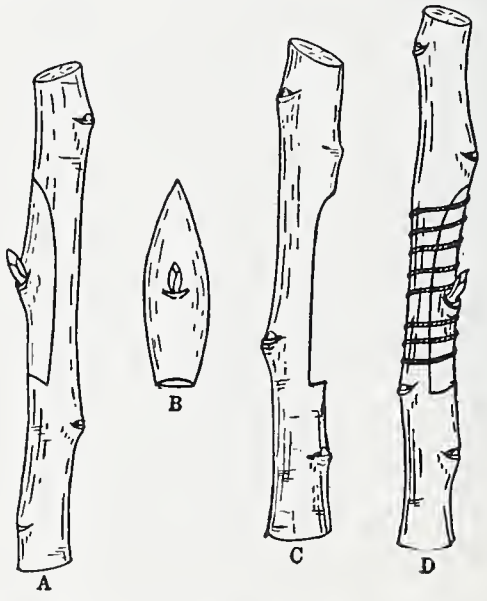

FIG. 76.—Steps in patch budding, often used with walnuts.

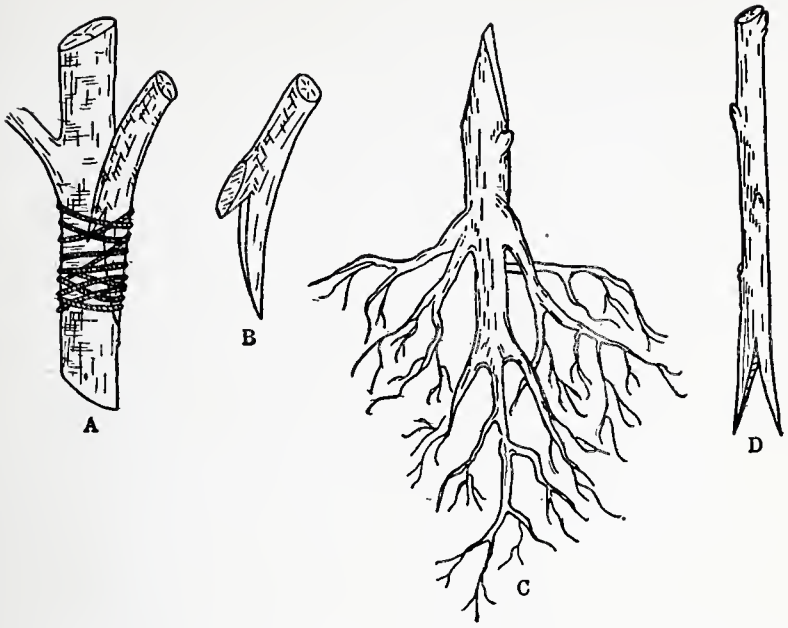

FIG. 77.—*A* and *B*, side grafting; *C* and *D*, saddle grafting. (Redrawn from Newsham.)

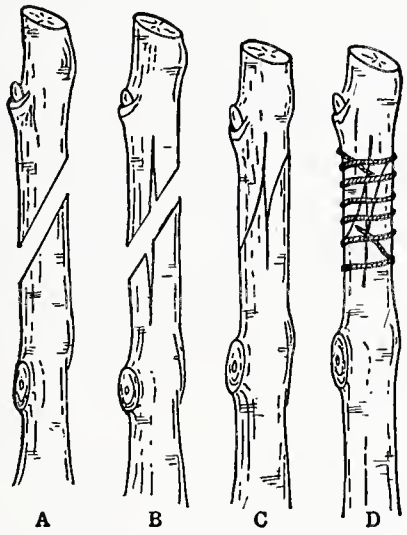

FIG. 78.—Steps in tongue or whip grafting.

hickory family. Plants belonging to different genera within the same family may or may not unite readily. For example, in the rose family, the peach will unite well with the plum, but not so satisfactorily with the apricot. The tomato and the potato may be intergrafted; they represent different genera in the family

Fig. 79.

Fig. 80.

Fig. 79.—Approach grafting, also known as inarching. The stock and scion are bound together, cuts being made in each (two stems at left), exposing the cambiums, to hasten union. (Redrawn from Kains, in *Plant Propagation.*)

Fig. 80.—Method of bridge grafting in a girdled trunk. Scions are inserted under the bark, thus bringing about a bridging of the girdled zone. (Redrawn from Solotaroff, in *Shade Trees in Towns and Cities.*)

Solanaceae. Plants belonging to different species within the same genus, as for example, crabapples and common apples, usually form a satisfactory graft union. And, different varieties of the same species, as for example, the different varieties of peaches, may be grafted upon one another. In short, as a general rule plants belonging to varieties of the same species graft upon one another

with greater certainty than plants of different species of the same genus, these in turn with greater certainty than those belonging to different genera of the same family; and plants belonging to different families will not unite at all by grafting.

It should be kept in mind that when two plants are united by grafting, each keeps its individual characters. If the crab-apple (scion) is grafted on the common apple (stock), the branches which arise from the scion will bear crab-apples and those from the stock, common apples.

In grafting, the stock may be the root, the crown, the main stem, the main branches, or the tips of the branches. There are many methods of joining the stock and scion, among which are the following: Whip or tongue, cleft, bark, kerf, veneer, splice, saddle, and bridge. In all of these methods, care is taken to bring the growing layers together and have them touch at as many points as possible.

CHAPTER XIV

WEEDS [1]

What is a Weed?—It is quite certain that everyone knows what a " weed " is; our conception of its meaning is very clear. We have come to consider as " weeds " those plants which tend to grow where they are not desired; plants which tend to resist man's efforts to subdue them; plants which will grow in most any kind of soil and under all conditions; plants which produce seeds in enormous numbers and have other rapid methods of propagation; plants in themselves sometimes truly beautiful, but which have for us lost their charm; plants useless and troublesome. Emerson said of a weed: " A plant whose virtues have not yet been discovered."

Losses Caused by Weeds.—The losses caused by weeds fall into two chief classes: (1) Losses brought about by a decrease in yield, (2) losses brought about by an increase in the labor cost of growing the crop.

Weeds Rob Cultivated Plants of Nutriment.—Weeds, as a rule, are vigorous growers and their demands for nutrients are great. Some weeds such as alfalfa dodders do not get their nourishment from the soil but have small root-like structures which penetrate the plants upon which they are growing and absorb nourishment from them directly. The dodders are parasites.

Weeds Rob Cultivated Plants of Water.—In the Western states where water is such an important factor in crop growth, and especially on non-irrigated lands, weeds do their greatest injury in using up the much-needed moisture.

The water requirements of many common crop plants and weeds have been determined by very careful experimentation.

[1] In this chapter free use has been made of material which appeared in publications by the author from the Colorado Agricultural Experiment Station.

It will be recalled that the water requirement of a plant is the number of pounds of water that must pass through the plant to produce one pound of dry matter. The table on page 175 gives the water requirements of a number of crop plants and weeds.

It will be seen from this table that the sunflower plant requires almost twice as much water as corn to produce the same amount of dry matter; the water requirement of ragweed is about three times that of millet; and of lamb's quarters fully twice as much as feterita. These figures show the injury that weeds do to our crops through their great demand upon soil moisture. In fact, the main benefit derived from cultivating corn and other crops is in the removal of weeds which compete with them for soil moisture.

Weeds Crowd Out and Shade Crop Plants.—By shading, weeds prevent crop plants from carrying on properly the work of food making. They may even prevent seedlings from getting a start. Moreover, shading may often favor the attacks of fungous pests.

Weeds Harbor Insect and Fungous Pests.—Insects and fungi often spread from weeds to neighboring cultivated plants. **Clean culture about roadsides, fence rows and ditch banks** is strongly recommended to prevent the spread of such pests. Insects deposit their eggs upon the weeds, and when the larvae hatch they migrate into the fields. Insects often go into hibernation somewhere near their native food plants, many of which are weeds, and from them they scatter to adjoining fields of cultivated plants. Insect pests gradually become thicker and thicker, and native plants being insufficient for their food supply, they move to adjacent fields of cultivated plants. For example, the **beet webworm** prefers lamb's quarters, Russian thistle and Atriplex rather than the sugar beet as plants upon which to deposit their eggs. Fields infested with or bordered by these weeds attract the moths, and when these plants are exhausted by the larvae, they move to nearby beets. It is worthy of note that lamb's quarters, Russian thistle and Atriplex belong to the same plant family as does the sugar beet. **White grub** does the most injury in those fields foul with grass. They lay their eggs in natural sod ground. **Grasshoppers** are always

worse next to ditchbanks and roadsides, fence rows, and other waste land, overgrown with weeds and grass. Grasshoppers rarely lay their eggs in cultivated fields, but select the native haunts in preference. **Potato bugs** flourish on greenberries, nightshade and buffalo bur. **False chinchbug,** which does great injury to seed crops, breeds and feeds during the early part of the season on shepherds' purse and other wild mustards.

It is now well established that the fungus causing stem rust of wheat is harbored by certain grasses such as wild barley and that it may spread from wild barley and other grasses to wheat. Certain wild mustards may serve as a host for the fungus causing " club-root " of cabbage.

Weeds Retard the Work of Harvesting Grain.—Weeds increase the pull for the horses, and cause an extra wear and tear on machinery. Witness the injury of this kind brought about by a heavy stand of sunflower or wild mustard in a grain field. Dodder may so mat alfalfa plants together as to make harvesting extremely difficult. Weeds increase the labor of threshing, and make an added cost in cleaning the seed.

Weeds and Dockage.—One of the most serious losses occasioned by weeds in fields results from the **infestation of the grain or seed crop.** The methods of estimating dockage at the elevators are now uniform. A sample of wheat is passed through the " kicker " and over a set of standard sieves, and the weed seeds, chaff, smut balls, etc., weighed, and the percentage of dockage determined.

The average dockage for wheat at the elevators in the Western states amounts to about 2 per cent. A large percentage of this dockage is wild oats, sunflower and other weed seeds. Farmers annually haul thousands of tons of weed seeds, chaff, and other inert matter to the mill in their wheat. And, of course, they are docked for this unclean wheat, and rightly so. Add to these losses those due to weed seeds in oats, rye, barley, alfalfa, millet, sorghums, and others, and one gains some idea of the tremendous losses due to unclean grain and seed. Moreover, unclean seed means that the fields which produced the seed were weedy. And, what is worse, it means that the next crop grown from such seed will be weedy.

Some Weeds Injure Stock.—The beards of downy brome grass, wild barley and certain other grasses may work into the gums of animals, causing ulcers and the loss of teeth (Fig. 81). Some weeds, such as cocklebur and sandbur, injure wool and disfigure the tails and manes of horses. A number of weeds are poisonous to stock (Fig. 82). Not only do such weeds decrease the crop yield, but when eaten may cause the death of stock. A rather prevalent weed along ditch banks throughout the country is water-hemlock, one of the most deadly of plants. The whorled milkweed, which has caused such tremendous losses of sheep on Western ranges, is rapidly becoming a pernicious weed in fields and orchards. It has also been found in hay.

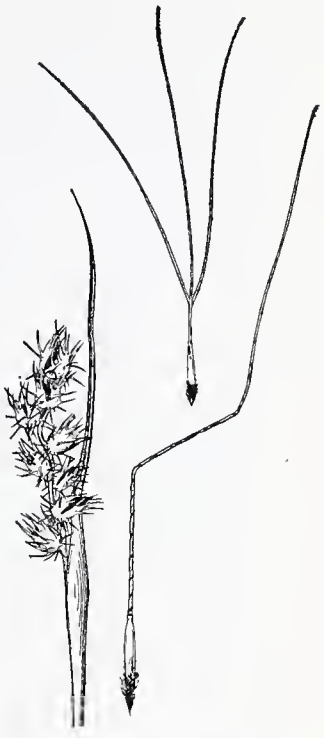

Fig. 81.—Seeds of mechanically injurious grasses. Left, sand bur; middle, three-awned grass; right, porcupine grass. (From Glover and Robbins, in Colo. Agr. Exp. Station Bulletin.)

Weeds Retard the Drying of Grain and Hay.—Many weeds are succulent and hold moisture and thus retard the drying of crop plants with which they are mixed.

Some Weed Seeds, Such as Cockle, Damage the Quality of Dairy Products.—Weeds such as wild onion and wild garlic, when eaten by cows, impart bad flavors to milk, butter and cheese.

Weeds Detract from the Appearance of the Farm.—A weedy farm is less liable to make a ready sale than a clean farm. If the tract is weedy, the purchaser will consider the cost of ridding it of weeds. It has been claimed by some that a farm which will grow weeds will grow crops of all kinds, or in other words, that the presence of weeds indicates fertile soil. The validity of this claim is very much open to question.

Weeds and Hay-fever.—We seldom think of the loss in personal efficiency and the annoyance which results from weeds to persons afflicted with hay-fever.

Fig. 82.—Purple loco, a stock-poisonous plant on Western ranges. (From Glover and Robbins, in Colo. Agr. Exp. Sta. Bulletin.)

Seed Production of Weeds.—Many weeds produce an enormous number of seeds. A large purslane plant will produce 1,250,000 seeds; a single Russian thistle plant will ripen 100,000

to 200,000 seeds; tumbling mustard, 1,500,000 seeds; shepherd's purse, 50,000.

The seeds of many weeds are very small and escape notice. A pound of clover dodder has 1,841,360 seeds; common plantain, 1,841,360 seeds; lamb's quarters, 604,786; Russian thistle, 266,817 seeds; wild mustard, 215,995 seeds; wild oats, 25,943 seeds. If 60 pounds of wheat are planted to the acre, and this wheat has 2 per cent of wild mustard seed, there will be distributed over that acre 388,791 mustard seeds, or 9 seeds in every square foot.

Vital Weed Seeds at Different Depths in the Soil.—Not only do weeds produce seeds in tremendous numbers, but seeds with an **ability to live a long time.** The seeds of some weeds, when buried in the soil, may retain their power of germination for 15 to 30 years. Such is true of the seeds of tall pigweed, black mustard, shepherd's purse, dock, yellow foxtail, chickweed, and others. The following table from the 1914 report of the Seed Commissioner of the Canadian Department of Agriculture refers to samples of soil which came from sod land, and shows the prevalence of weed seeds in farm lands.

Depth of samples	Av. No. vital noxious seeds in 20 ounces	Av. No. vital seeds of all kinds in 20 ounces	Av. No. vital seeds of all kinds in piece of land 1 yd. square by 1 inch thick
1st inch...	2.2	24.4	1106.7
2–3 inches.	2.4	10.2	456.5
5–7 inches.	0.9	7.3	331.4

Some Weed Seeds Exhibit Dormancy.—All the seeds of a given crop of seed may not germinate the first year; some may remain alive in the ground for a time. This has been given popular expression in the following statement: "One year of seed gives 7 years of weeds." All the seeds of wild oats may not germinate the year produced. The same holds true of many seeds of tall pigweed, cocklebur, and others.

There is a notion prevalent that wheat turns to chess, for it is frequently noticed that the weed comes in where perfectly clean wheat seed has been sown. This is due to the fact that chess seed retains its vitality in the soil for a long period. The soil may have been infected with chess seed a number of years previous to its first appearance in the field, the conditions at the time being unfavorable to its germination. Later, conditions were suitable for its germination. Wheat does not change to chess.

Weeds as a Class Are Hardy.—Weeds are resistant to insect and fungus pests. They also have the ability to withstand shading, excessive drought, temperature extremes, and other unfavorable conditions. Of all weedy plants, the worst are those with underground stems or rootstocks, which live over from year to year in the soil, and enable the plant to spread rapidly in all directions underground. These underground stems store food, and, although the plant is cut off above ground, new stems are sent up directly from below. **Weeds with rootstocks are particularly difficult to eradicate.** Well known examples of such weeds are poverty weed and Canada thistle.

Many Weeds Have a Disagreeable Taste or Odor, or Bear Prickles.—Animals pass by such weeds. Hence, the weeds occupy the ground and multiply. Examples of such weeds are milkweed, gumweed, buffalo-bur, dog-fennel, and ragweed.

Weeds Travel Rapidly.—It has been the history of nearly all agricultural communities that weeds increase in abundance and variety, unless concerted action is taken to combat them. Almost every year sees the first appearance of some weed in a community, and usually in a few years it is prevalent. Consider Russian thistle, for example. In Colorado, the plant first attracted notice in the fall of 1892, at Denver, LaSalle, and Longmont, where it was found along railroad tracks. It is said to have been introduced into Morgan County, Colorado, by a colony of Russians, who brought it as an impurity in seed from the northern part of the Mississippi Valley. Since 1892 the plant has spread throughout the agricultural sections of the West, and in some localities is a menace. In fact, some sections are being abandoned on account of the Russian thistle. Russian

thistle seeds are now a common impurity of crop seeds. The entire plant may break off at the ground line, become a "tumble weed," and be blown for miles across the open country, distributing its seeds as it tumbles along.

Weeds Have Excellent Means of Seed Dispersal.—It would take pages to describe adequately the many contrivances which weeds have for distributing their seeds. As stated in Chapter XII some seeds like those of the thistle, milkweed, sow-thistle, wild lettuce, and dandelion, have cottony or feather-like attachments which enable them to take long aerial journeys. Most seeds will float on water and, consequently, are carried by streams and irrigation waters. A number of seeds are provided with hooked prickles or barbs by which they attach themselves to the clothing of man or the hair of animals, and are thus carried from place to place.

Impure Commercial Seeds.—*There is probably no other means of introducing weeds so effective as the sale and distribution of impure commercial seeds.*

Seeds Are Carried in Screenings, Baled Hay, the Packing about Trees and in Feed Stuffs.—Some seeds are uninjured in passing through the digestive tracts of animals and consequently are spread on the field in manure. The use of feeding stuffs containing live seeds may result in the spread of noxious weeds. A threshing machine may carry weed seed from farm to farm. Some weeds are dragged by plows, cultivators, and harrows from one part of the field to another and even to adjacent farms. This is true of those perennial weeds with underground stems which are cut up into pieces by cultivating implements.

Wind and Water Are Important Agents in Weed Dissemination.—Wind carries seeds, and in some instances whole plants, long distances. In the irrigated sections, **water is one of the chief means of spreading seeds.** Ditch banks are densely overgrown with weeds, which shed their seeds in the water; the seeds are carried down stream, given a good soaking in transit and planted on a well-soaked soil—all conditions being ideal for germination.

Birds May be Responsible for the Distribution of Weed Seeds.—Birds, however, probably do more good in eating weed seeds than harm in distributing them.

Underground Spreading of Weeds.—Perennial weeds, such as Canada thistle, **travel considerable distances each year underground.** A small patch in one corner of a field may appear harmless enough, but it may soon spread over a whole field by means of underground growth alone.

Classes of Weeds.—Weeds fall into three classes according to their length of life. It is necessary to know to which class a weed belongs before one can wisely proceed to eradicate it. These weed classes are:

1. *Annuals.*—Those that live one year, such as Russian thistle, pigweed, wild oats, shepherd's purse, pepper-grass, foxtail, and ragweed.

2. *Biennials.*—Those that live two years, producing seed at the end of the second year, such as wild carrot, wild parsnip, mullein, and bull-thistle.

3. *Perennials.*—Those that live from year to year by means of underground parts. They are our worst weeds, and when once established are difficult to eradicate. Some common perennial weeds are wild morning-glory, or bindweed, poverty weed, Bermuda grass, dandelion, sow-thistle, and Canada thistle.

Annuals and Biennials.—Annual and biennial weeds produce seed but once and then die down entirely, root and all. **They propagate themselves by seed alone.** Consequently, all methods of controlling weeds of these two classes have for their object the **prevention of seeding.** Clearly, if they are kept from seeding, and pains are taken to prevent seeds from being introduced to the land in the many ways that are possible, annuals and biennials are kept in check on the farm.

Annuals and biennials are easily killed by cultivation. The seeds of some weeds of these classes retain their vitality in the soil for several years, consequently several years of cultivation may be necessary. The principle of eradication of annuals and biennials is to prevent seeding, and to cause the seeds that are shed to germinate and then destroy the seedlings before they are

mature. The following annuals have seeds which retain their vitality a long time in the soil: Wild oats, tall pigweed, black mustard, shepherd's purse, dock, yellow foxtail, and chickweed. The following have seeds of short vitality: Lamb's quarters, wild buckwheat, Russian thistle, smartweed, and prickly lettuce.

There are two kinds of annuals: Summer annuals and winter annuals. **Summer annuals** germinate their seeds in the spring, produce a crop of seed in the late summer or fall and die down. The seedlings are not capable of living through the winter season. Russian thistle, foxtail grass, frenchweed or fanweed, barnyard grass, witch-grass, pigweed, and lamb's quarters are common summer annuals. **Winter annuals** come up from seed in the fall and live over the winter in the seedling stage, producing flowers and fruit the following spring or early summer. They have the habit of winter grain. Shepherd's purse, pepper-grass, and prickly lettuce belong to this class. The seeds of winter annuals germinate after fall rains, and the young seedlings are easily killed at this time by cultivation. Winter annuals frequent stubble fields.

Perennials.—As has been stated, perennial weeds live from year to year without renewal from seed. **They propagate themselves by means of both seed and vegetative growth (roots and underground stems).** It is not sufficient to prevent seeding alone, although **this should be done.** All methods of holding in check or eradicating perennial weeds have for their object the **starving or smothering of the underground growth.** It is well-known that if the top growth of a perennial weed is cut off, new shoots are sent up from the stems or roots beneath ground. This means, then, that the underground parts possess reserve food material which is called upon to produce new shoots. As soon as leaves are produced on the new shoots, the manufacture of food is begun by them, and some of this food, made in leaves, finds its way back into the roots or rootstocks which thereby gain in strength. A rootstock or perennial root will increase in size each year just as does a perennial stem above ground; and the larger it gets, the more difficult it is to starve out. Old, well-established perennial weeds are very difficult to eradicate, for the reason that they have a large store of reserve food to draw

upon in the production of one crop of leafy shoots after another. It is a common experience that one may, by a thorough cultivation, kill all the top growth of a perennial weed, and find that the plant soon comes up thicker than before. A second thorough cultivation may be followed by like results. The farmer is of course inclined then to become discouraged. He says, "What is the use; cultivation only aggravates the trouble," and he gives up.

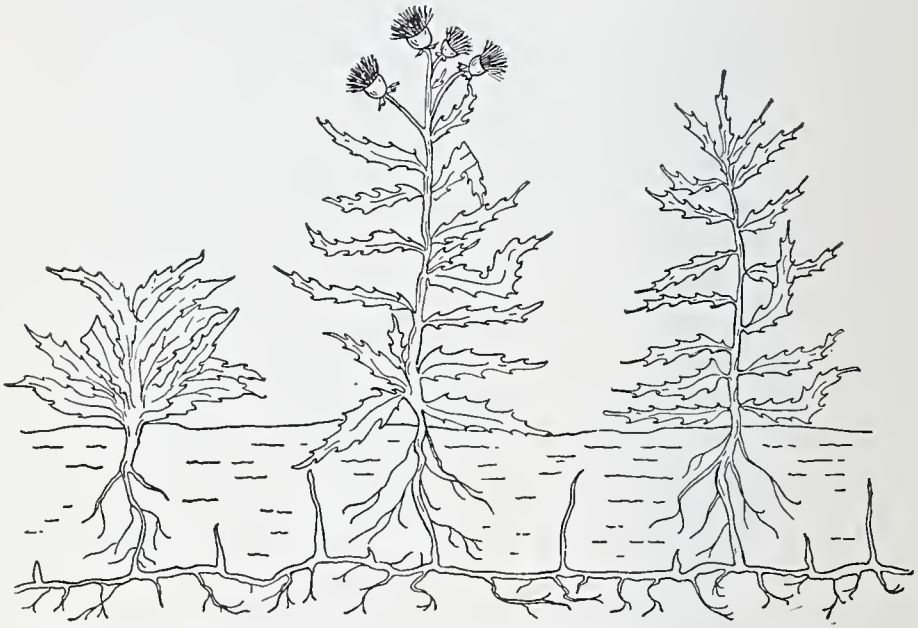

FIG. 83.—Canada thistle, a perennial weed that propagates both by seeds and underground stems. The illustration shows three different ages of shoots that have arisen from the underground stem and reached the surface, and several others which have not yet reached the surface.

He was on the right road, but stopped too soon. Each time that top growth was removed and new shoots sent forth, reserve food in the roots and rootstocks was used up. What is needed in the eradication of a well-established perennial weed is persistence and patience, cultivation frequent enough to keep down all leafy shoots, and no stopping until the object is attained. This may mean a season or two of bare fallow, followed by a crop

which will permit of clean cultivation. Some farmers place in a cultivated crop like corn, potatoes, beets or beans but do not cultivate often enough and thorough enough to prevent perennial weeds making headway.

Small patches of perennial weeds can be eradicated by spading up the soil, raking out and burning the underground parts, and hoeing off every sprout as soon as it appears, during at least two seasons.

Large areas that are badly infested should be deeply plowed just when the plant comes into bloom, turning it under completely. In a few days the land should be thoroughly disked and this operation should be repeated at least once a week for six or seven weeks, then less frequently until the end of the growing season. Places which can not be reached with the plow and disk must be spaded and hoed by hand. It is well to go over the ground every three or four days and hoe off every sprout that appears above the surface; otherwise, the plant will partially recover.

In some places where perennial weeds, such as the wild morning glory; are particularly bad, a cultivator equipped with knives has been employed (Fig. 84). Shallow cultivation is given frequently, sometimes as often as twice a week, with this implement. The tool has proven to be very effective in keeping down all weed growth, and its use should be more generally adopted.

The following season the land may be bare fallowed if weeds are still bad, or planted to some crop which will permit of perfectly clean cultivation. Great care must be taken to keep down every sprout of the plant as soon as it shows above ground. The thoroughness with which the work is done will determine the success or failure of the attempt. Careful watch should be kept during several years to see that none of the plant has escaped the hoe and become established anew.

Use of Clean Seed.—The first principle in weed control is the use of **clean seed.** A lot of "clean seed" is one which contains only the larger and plumper seeds of the crop desired, and is free from sticks, stones, gravel, dirt, chaff, weed seeds, the seeds of other crops, smut balls, and from small, shrunken seeds of the crop desired.

It is possible to secure seed free from noxious weed seeds. **Dirty seed can be made clean.** A fanning mill properly operated will do the job. It is far easier to remove weed

FIG. 84.—An efficient four-horse weeder used in morning glory control. (From Barnum, in Calif. Agr. Exp. Station Bulletin.)

seeds from crop seeds than it is to take the weeds from the fields.

Preventing Weeds from Seeding.—The second principle in weed control is the prevention of seeding. This means the use

of a hoed crop or meadow crop. Weeds in small grain can not be prevented from seeding; as a result, continuous cropping to grain leads to foul fields. It is the inevitable result of a one-crop system.

Cutting the Weeds along Roadsides and Fences.—Throughout our entire country, cultivated fields are surrounded or bordered by areas infested with weeds. Roadsides are the chief sources of weed seed supply. It is true that states and counties have laws which require the mowing of weeds along roadways prior to their seeding. But in very few instances is the regulation adequately enforced. As a matter of fact, weeds come to maturity and stand man-high along our roadsides, contaminating the adjacent cultivated fields.

Cutting the Weeds along Ditch Banks.—Irrigation water is one of the chief means of spreading seeds in the Western States. Practically all ditch banks abound in weeds. The seeds are shed into the water, carried down-stream and on to cultivated fields. They have been soaked up in transit and spread on a moist soil, where they readily germinate. That there should be a regulation requiring the mowing of weeds along roadsides and not one compelling the removal of weeds from ditchbanks is inconsistent. Many of the ditches can be fenced and the enclosed area pastured to sheep.

Giving Special Attention to Manure and Screenings.—The seeds of many weeds are not injured by passage through the digestive tract of an animal. Consequently, weedy hay, weedy bedding, grain carrying weed seeds, or unground screenings are a source of contamination. Many stock foods contain unground screenings in which may be found many small weed seeds, such as the plantain. Cases are known in which the weed seeds from this source have been carried to the field in the manure. Wild oats, for example, is carried to the field in this manner. Well-composted manure contains no visible seeds. All screenings containing weed seeds should be thoroughly ground or steamed before they are fed. It should be added here that weed seeds are destroyed by the fermentation processes which ensilage undergoes.

Destruction of Seed Already Shed.—It is very difficult to prevent the seeding of weeds, especially in a grain crop. Wild oats and mustard nearly always mature and shed their seeds before the crop is ready to harvest. Consequently, the soil is seeded with seeds.

If the soil contains weed seeds, a good plan is to prepare the seed bed in the fall, making it favorable for germination. Thus, the weed seeds are induced to germinate, and the young seedlings are subsequently destroyed by disking. A practice in irrigated sections is to irrigate grain land immediately after the crop is harvested to induce weed seed germination. The younger the weeds, the more easily they are subdued.

If stubble fields are disked in the fall as soon as the crop is removed, many seeds are caused to germinate and the seedlings are killed by frost or by subsequent cultivation. Summer annual seedlings will likely be killed by frost, while winter annuals will require subsequent disking. Similarly, spring cultivation will stimulate the germination of seeds which failed to germinate the previous fall, and the seedlings may be easily killed by later cultivation.

Mature seeds should never be plowed under with a view of smothering them by deep burial. Many weed seeds retain their vitality for years and years in the soil. Subsequent cultivation may bring them to the surface.

Many weeds in stubble are destroyed by pasturing. Sheep are particularly effective. Also, a number of weed seeds are trampled into the soil and caused to germinate. The young seedlings are eaten, or destroyed by frost. Bindweed has been quite successfully reduced by pasturing to hogs, with noses unrung. The hogs like the roots and rootstocks. It is often better to plow the infested area before turning in the hogs. The soil is loosened and the hogs can root more easily.

Use of Cultivated or Cleaning Crops.—Crops such as beets, potatoes, beans and corn which permit frequent cultivation are rightly called **cleaning crops.** Practically all annual and biennial weeds readily succumb to cultivation, and perennials are effectively held in check. Continuous cropping, particularly to small grain,

which does not allow cultivation, inevitably leads to weedy fields. Cultivated crops are a necessity in any scheme to eradicate weeds.

Rotation of Crops.—"Crop rotation" is practically a synonym of "good farming." In fact, the control of weeds is one of the principal reasons for crop rotating. There are farms on which weeds are of little consideration, either in increasing the labor expended or in decreasing crop yields. And these farms are ones on which a definite plan of crop rotation is systematically adhered to. One can not expect to have no trouble with weeds and follow a continuous system of cropping. Even old stands of alfalfa frequently become weedy, and must be plowed up and placed in a cultivated or cleaning crop.

There are three main classes of field crops:

1. *Grass Crops.*—Alfalfa and other legumes used as forage, and grasses.

2. *Grain Crops.*—Wheat, oats, barley, rye, sorghums, millet, and flax.

3. *Cultivated Crops.*—Potatoes, beets, beans, peas, corn and sometimes sorghums.

The grass crops, particularly alfalfa, are extremely useful in weed control in that they crowd out or smother the weeds. Moreover, they permit of several cuttings a season, which will tend to keep weeds from making headway. Very few weeds are able to compete favorably with a heavy stand of alfalfa. However, there are some weeds, such as fanweed, dandelion, and wild mustard, which are not crowded out by alfalfa, but make their way into alfalfa, particularly old stands. Consequently, it is inadvisable to leave alfalfa in for a long time especially where these weeds are prevalent.

The grain crops favor the growth and increase of weeds, for the reason that a number of weeds mature and shatter their seeds before the grain is mature.

The cultivated crops are the weed eradicators. They should be introduced into the cropping system if for no other purpose than that of elimination of weeds. However, a cultivated crop should not be grown continuously for a number of years on the

same land for the supply of humus is seriously decreased thereby. Moreover, it is well known that nearly every crop has its own accompanying weeds, which are much less abundant in other crops. Accordingly, if a given crop is grown year after year on the same piece of land, the weeds peculiar to it increase in abundance.

CHAPTER XV

WATER AS RELATED TO PLANT LIFE

THERE is probably no single factor that gives the grower of plants so much concern as that of water. His yields are very greatly determined by the amount of precipitation and its seasonal distribution, or by the amount of irrigation water applied to the soil. So he is necessarily very much interested in the effect of water upon plant growth and in such questions as the following: What is the water problem of the plant? How does soil type influence the availability of soil water? What conditions affect the rate at which a plant absorbs water from the soil? What conditions affect the rate at which a plant loses water to the atmosphere? How do crop plants differ in their water requirements? What are some of the practical ways by which the grower can increase or conserve the water supply in the soil? What are the characters which enable a plant to evade or resist drought?

In Chapter I we stated that the grower is concerned not only with the **structure and work of the living plant,** but also with that complex set of factors we call the **environment** and the influence it has on the plant. Here and there, as it seemed desirable, we have given the influence of various environmental conditions, such as light, heat, water, etc., upon structure and function. It is now our purpose in the next few chapters to discuss more fully certain important factors which affect plants.

The important environmental conditions which affect the growth of a given plant or crop have been classified by the famous botanist, Warming, as follows:

1. **Atmospheric factors,** such as
   (*a*) Light
   (*b*) Temperature

(*c*) Atmospheric humidity and precipitation
(*d*) Movements of the air

2. **Soil factors,** such as
(*a*) Water supply
(*b*) Air supply
(*c*) Temperature
(*d*) Plant nutrients

In addition to these we must add the influence of plant and animal diseases, of beneficial plants and animals, both within the soil and above it, and of man himself.

Importance of Water in the Life of the Plant.—Life without water is impossible. Water is the principal part of all living tissue. It constitutes about 80 to 90 per cent of the weight of protoplasm. As we have seen, it is an essential raw material in the manufacture of food. All mineral salts must be dissolved in water before they can enter the plant through the root hairs. Oxygen and carbon dioxide can not enter or leave the plant except in solution. Water serves as a medium of distribution throughout the plant of mineral salts and foods. Water in the living cells maintains their turgor, which condition is necessary for their proper functioning. The brittleness of young plants is partly due to water pressure within the cells.

Water is the chief limiting factor in the growth of most crops. For the majority of crops, there is ample sunshine, and an abundance of oxygen and carbon oxide in the air; the temperature of the air and soil is seldom seriously unfavorable; as a rule, there are sufficient nutrients in the soil; but the farmer, except in the most rainy sections of the country, is usually confronted at some time during the season with a shortage of water. This is particularly true in arid and semi-arid regions.

Water is a most important factor determining the distribution of plants over the earth's surface. The striking differences in the vegetation of the high mountains, the dry plains, the prairies, the eastern deciduous belt; in the character of the plant life of tropical rain forests, deserts and tundra; in the vegetation of hill-side, brook-bank, gravel slope, bog, meadow, and open water are largely due to differences in the available water supply.

Amount of Water in Plants.—The amount of water in different plants varies widely. As a rule, plants growing under dry conditions contain less water in proportion to their total weight than plants growing in wet situations. However, many desert plants, such as cacti, may possess large amounts of stored waters. The percentage of water is usually greater in young, growing parts than in older portions of the same plant. Seeds and woody tissues contain less water than the leaves or young roots and stems. Toughness of tissue is usually associated with a low water content of the tissue. Succulency and tenderness of tissue usually signifies a high water content.

Average Per Cent of Water in Some Common Plants or Plant Products

Apples (fruit)	83.2	Corn fodder (green)	79.8
Buckwheat (grain)	12.6	Corn (grain)	10.9
Flax (seed)	9.1	Cucumbers	96.0
Potato (tuber)	75.0	Onions	87.6
Beet (sugar)	86.5	Wheat grain (full-ripe)	12.97
Cabbage	90.5	Wheat grain (milk-ripe)	47.69
Alfalfa (fresh)	73.14		

The Water Problem of the Plant.—It is quite clear that one of the chief problems of a plant is to take in at least as much water as it gives off. Of course, the intake must exceed the outgo, for some of the water is used in the plant. Absorption must at least equal transpiration, if the plant is to maintain life. The great dangers that confront most plants, particularly dry-land plants, or those subject to dry periods, are too little absorption or too much transpiration. A plant dies when for any length of time the rate of water loss exceeds the rate of water intake.

There is a stream of water through the plant from root hairs to leaves. Its rate of flow may be limited or restricted at two points: (1) At the point of entry (root hairs), and (2) at the point of exit (leaves). Plants withstand dryness in two general ways: (1) By increasing the amount of water taken in through the roots. (2) By limiting or retarding the amount of water lost from the plant.

The Wilting of Plants.—A plant tissue is made up of a mass of cells. When a cell is filled with water and various materials in solution, its walls are bulged outward and we say that the cell is turgid. If the water is removed from the cell, it becomes flaccid and wilts. If all the cells of a herbaceous plant are filled full of water, each cell wall being stretched out because of the pressure from within, the plant as a whole stands erect. Of course, it must be understood that most plants possess strengthening woody tissue and are not entirely dependent upon turgor to hold them in an erect position. But the leaves of all plants are largely dependent upon the turgor of the cells for their rigidity.

When a plant wilts it is not absorbing water as rapidly as it is lost. Its cells are not full. The freshness and crispness of lettuce, for example, is associated with turgidity on the part of the leaves. Any means by which transpiration can be checked, such as by a cool atmosphere laden with moisture, will prevent wilting to a large extent.

Intake of Water.—All the water taken in by crop plants comes through their roots. By far the largest proportion comes in through the thin-walled root-hairs.

There are many conditions which determine the intake of water, the principal ones of which are discussed in the following paragraphs:

Available Water in the Soil.—It is a well-known fact that of the total amount of water in the soil all is not available for plant growth. And, there is no direct relation between the percentage of water in the soil and the amount available for plant growth. If we allow a plant to grow in a soil until it undergoes wilting, to the extent that it will not recover in an approximately saturated atmosphere, or will not revive until water is added to the soil, we find that considerable water is still left in the soil. This is water that the plant can not get readily, and at this point the plant shows distress. The water is in the soil, but the plant is unable to remove it and utilize it readily for **growth.** Hence as far as the plant is concerned, the soil is dry. The percentage of water left in a soil at the time the plant undergoes permanent

wilting is spoken of as the **wilting coefficient.** This wilting is not the same as temporary wilting which must frequently take place when the air is very dry.

The amount of water **available** for **growth** varies with the soil. A plant can reduce the water content of a sandy soil to a lower point than it can that of a clay soil. That is, when a plant growing in a sandy soil has used all the water it can for growth purposes, the percentage left in the soil is smaller than that left in a clay soil under similar conditions. The table accompanying shows this point.

Type of Soil	Wilting Coefficient, Per Cent
Coarse sand	0.9
Fine sand	2.6
Sandy loam	8.3
Loam	11.0
Clay loam	13.6

From this table it is seen that after a plant has used all the water it can, without permanently wilting, in a sandy loam there is left in that soil but 8.3 per cent of water. On the other hand, the same plant growing in a clay loam wilts at a moisture content of 13.6 per cent. Looking at this in another way, a sandy loam having 15 per cent total water would be much "wetter," as far as the plant is concerned, than a clay loam with 16 per cent total water. For, the plant growing in a sandy loam with 15 per cent total water can reduce it to 7.8 or 9 per cent; the same plant growing in a clay loam would wilt when the water content was reduced to only 13.6 per cent.

The above facts emphasize the need of knowing, not only how much the total water in a soil is, but also how much of it is available for the growth of the plant. The moisture content which corresponds to the wilting coefficient is a perceptably dry condition in most soils and one at which anyone would judge the soil to be in need of water.

But there are other considerations. For a long while it was thought that the greater drought resistance of one plant as compared with another was due to the greater ability of that plant

to absorb water from the soil. It has been demonstrated that different plants growing in a **similar** soil and under **similar** conditions have approximately the same wilting coefficient. In other words, that they reduce the percentage of water to about the same figures. This is shown in the following table, which gives the relative wilting coefficients for different crops. The ability of a plant to resist drought apparently does not depend upon its power to extract water from a soil.

Wilting Coefficient of Sand Loam (Data from Briggs and Shantz)

Kind of Plant	Wilting Coefficient, Per Cent
Corn (Boone County White)	6.5
Sorghum (Dwarf Milo)	5.9
Wheat (Kubanka)	6.3
Oats (Kherson)	5.9
Barley (Beldi)	6.3
Rye (Giant Winter)	5.9
Pea (Canada Field)	6.9
Vetch (Vicia Faba)	6.1
Tomato (Stone)	6.9

Power of Soil to Deliver Water.—If moisture is absorbed by the root hairs from the adjacent soil particles at a very rapid rate, as will be the case on hot, dry days, it may not move from remote soil layers rapidly enough to supply that lost. It is clear that under this circumstance the soil immediately surrounding the root hairs will become too dry to give up more moisture. Water moves from soil particle to soil particle more rapidly in some soils than in others. The finer the soil, the slower are all water movements through it, but the extent of the movement may be greater.

Extent of the Root System.—The character of the root systems of plants varies widely. There are root systems (1) that penetrate deeply in the soil; and (2) those that are confined to the surface layers. Some plants do not suffer from drought, because of their ability to send their roots into the deeper and

moister soil layers. Such a plant is alfalfa. If, on the other hand, the soil is shallow and the rainfall slight the plants with a shallow root system may be somewhat more successful than deep-rooted sorts, on account of their ability to take advantage of the water that comes to the soil in the form of occasional light showers. It must be remembered that the depth of the root system is an inherited character of the plant, and is independent, to some extent at least, of external conditions. Root development, however, will not take place in a dry soil.

Temperature of the Soil Water.—The rate of absorption is lowered by a decrease in the soil temperature. A plant may wilt in a soil saturated with water, if the temperature of the soil sinks below a certain degree. In cold, dry climates winter killing may be the result of a cold soil, which slows up absorption, accompanied by a high transpiration rate. It is believed that in winter killing the plant is as frequently killed by direct drying, as by actual freezing.

Concentration of the Soil Solution.—Water passes from the soil through the living membrane of the root hair cells into the plant. This process of water intake goes on as long as the total concentration of the cell sap is greater than the total concentration of the soil solution surrounding the root hairs. Other things being equal, the greater the concentration of the cell sap as compared with that of the soil solution, the more rapid the water intake. As the concentration of the soil solution approaches that of the cell sap, the rate of absorption slows down. Plants growing in an " alkali " soil are exposed to a soil solution of high concentration. Hence absorption is retarded. There may be plenty of water present in the soil, but the plant gets it with difficulty, on account of the high concentration of the soil solution. Plants of alkali flats and swamps usually show the same adaptations to drought displayed by plants growing under desert and semi-desert conditions.

Likewise, bog plants are growing in a medium which retards water intake. This may be due sometimes to the high concentration of bog waters, but more often to toxic substances in the soil, which hinder root development.

The Rate of Transpiration.—If a plant loses water rapidly, as will be the case on a hot, dry day, the rate of absorption and movement through the plant will be correspondingly rapid.

The Water Outgo of Plants.—Water may leave plants in two physical forms: as a **liquid,** and as a **vapor** (gas). We are familiar with the "bleeding" of trees that have been wounded, and there are some plants of the very moist tropics which exude water naturally in large drops from the leaves. Disregarding these few cases of water loss in a liquid form, it can be said that practically all plants, and indeed all of our crop plants, lose water only in the vapor form. Slight amounts of water pass off from the surface cuticle, but almost all of it leaves the plant through the stomates of the leaf. This water-losing process we designate **transpiration.** It is nothing more or less than **evaporation under control by the leaf.** The same factors which affect the rate of evaporation will also control the rate of transpiration. These factors are as follows:

1. *Relative Humidity.*—By relative humidity is meant the amount of moisture in the air at a given temperature as compared with what it can hold at that temperature. A relative humidity of 50 per cent means that the air is holding just one-half as much moisture as is possible for it to hold at that temperature. If the relative humidity is low, for example, about 30 to 40 per cent, it means that the air is dry; and, transpiration or loss of water from the leaves will be rapid. If the air is saturated, that is, has a relative humidity of 100 per cent, little water will be lost.

2. *Temperature of the Air.*—The relative humidity is affected by the air temperature. If the air warms up, its water holding capacity increases, which consequently lowers the relative humidity. Other things being equal, transpiration goes on more rapidly at a high than at a low temperature. However, even at very low temperatures, some water is lost by the plant.

3. *Air Movements.*—Transpiration is greatly accelerated by a high wind. A current of air about a transpiring leaf constantly removes the layers of moisture laden air, immediately surrounding the leaf, while it brings to it air that is not so filled with water. Along windy shores, on plains, mountain peaks and exposed

situations, transpiration goes on at a high rate. However, it must not be assumed that the transpiration increases in proportion to the wind movement.

4. *Intensity of Light.*—An intense light increases the rate of transpiration.

The Water Requirement of Plants.—Plants differ greatly in the total amount of water which is expended in producing a unit of dry matter. Some plants, like millet, are economical, others like alfalfa are comparatively uneconomical. The water requirements of a number of plants have been determined experimentally. In the following table is given the water requirement of a number of plants under certain conditions as they existed at Akron, Colorado. For different climatic conditions these values will be somewhat different.

	Actual Water Requirement (Pounds)	Relative Water Requirement as Compared with Kubanka Wheat
Alfalfa, Grimm	659	1.67
Rye, Spring	496	1.26
Oats, Swedish Select	423	1.07
Barley, Beardless	403	1.02
Wheat, Kubanka	394	1.00
Wheat, Kharkov	365	0.93
Corn, China White	315	0.80
Wheat, Turkey	364	0.92
Sudan grass	359	0.91
Milo, Dwarf	273	0.69
Kaoliang, Brown	223	0.57
Millet, German	248	0.63
Proso	208	0.53

It will be observed from this table that alfalfa, for example, uses about three times as much water to produce a unit of dry matter as does Proso. In general, a plant with a low water requirement is relatively drought resistant.

The water requirement of a plant is influenced by a number of factors. It is less in a humid climate or where there is much cloudy weather than in an arid climate. That is, it is less where the loss of water by transpiration is low, but where other conditions for growth are favorable. It is the belief of some that the water requirement is less in a fertile soil than in an infertile soil. A diseased plant has a greater water requirement than a healthy one.

Man's Control of the Water Relation.—As has been said, water is the chief limiting factor in the growth of most crops. The relation plants bear to water is a most significant one. Plant responses, in whatever form they manifest themselves, are largely responses to water, to the absorption-transpiration ratio. The distribution of plants over the surface of the earth, the general appearance and behavior of plants, the success or failure of crop plants, all are very intimately related to the absorption-transpiration ratio.

It is not to be wondered at then that many of man's agricultural operations have as their aim the control of the water relation. These operations may be divided into two groups.

1. Those which aim to increase the water supply.
2. Those which aim to decrease the water supply.

The water supply in the soil may be increased or conserved by (1) direct application of water (irrigation), by (2) reducing the evaporation from the soil, by (3) reducing the loss from percolation, and by (4) increasing the capacity of the soil for water.

Irrigation.—The practice of irrigation dates back to very early times. It has been most extensively developed in the semi-arid and arid regions of the world, although it is not confined to these sections. There are many methods of distributing and applying water to the soil. They have been grouped under four general heads: (1) Flooding, (2) furrow distribution, (3) sub-irrigation, (4) sprinkling.

The **flooding method** is of course most applicable to alfalfa and other hay crops, to small grain, to rice and cranberries. The water may be allowed to stand for a period on rice and cranberry fields, whereas it is intermittently applied to hay and grain crops.

One of the common flooding methods is the application of water to each tree in a basin (Fig. 85).

The hoed crops, such as potatoes, beets, corn and beans, and the orchard fruits, small fruits and truck gardens are best irrigated by the **furrow method** (Fig. 86). It is a very economical

FIG. 85.—Flooding method of irrigation in which water is applied to each tree in a basin. (From Division of Irrigation Investigations and Practice, College of Agriculture, University of California.)

way to distribute water, is a convenient method to use, and there is little danger of injury to the crop.

Sub-irrigation is carried on by underground pipes or tile, or by ditches in which the water is brought, thus raising the water table over an entire area. The use of pipes or tiles is not practicable for any of the ordinary farm crops on account of the excessive cost of installation. The method is employed only in most intensive farming. Sub-irrigation by ditches is successfully

carried on in the low lands of the Sacramento and San Joaquin Valleys of California.

The **sprinkling method** is used quite extensively in humid sections. The area to be irrigated is equipped with a piping system and at the proper intervals are spray nozzles (Fig. 87). There must be a rather heavy water pressure. The system is expensive to install and to operate and can only be used practically with special crops.

Reducing the Loss of Water from the Soil.—When the soil is wet either by natural precipitation or by irrigation, there is often

FIG. 86.—Furrow irrigation.

some run-off, and under certain conditions some of the water is pulled down by the force of gravity out of reach of the roots. Then the surface layers of soil begin to lose water by evaporation to the atmosphere. But once the surface layer of soil becomes dry, there is almost no further loss from deeper layers to the atmosphere, **if the soil is devoid of vegetation.** It is well known that the principal loss of water from the soil is through the plant. It is the water that is absorbed by the roots that passes through the plant and out chiefly through the stomates in the leaves to the atmosphere. It has been demonstrated that the loss of water

from a given area of soil covered with plants is greater than that from an equal area of soil bare of vegetation. A plant covering increases the water-losing surface of the area, and furthermore takes moisture from the deeper layers.

In dry land farming it has been found that "destroying weeds was more important than maintaining a mulch in conserving moisture in fallow land." In fact, weeds are a most important factor in dry-land farming. Often the soil will retain as much moisture where the weeds are pulled as where the soil is culti-

FIG. 87.—Sprinkling method of irrigation. (From Division of Irrigation Investigations and Practice, College of Agriculture, University of California.)

vated. In raspberry culture, the development of new canes is seriously interfered with by grass and weeds which consume soil moisture. The great benefits of tillage seem to be the removal of weeds which take water from the soil.

Mulches are used to prevent loss of water from surface layers of soil and from low-lying plants. There are two sorts of mulches: (*a*) **non-living material,** such as manure, straw, dead plants, leaves, etc., and (*b*) **those formed from natural soil.** It is the common practice in those sections experiencing cold, dry winters to cover strawberries, raspberries, and other low-lying perennial plants

with a mulch of straw, leaves or manure. The canes of raspberries are more commonly mulched with soil.

The soil mulch is used in the belief that it checks evaporation from the soil. It is supposed that by frequent stirring of the surface soil, a mulch is prepared which prevents evaporation of water from below. Light showers are thought to affect the formation of a surface crust on the soil, which is believed to be harmful in that it establishes a capillary connection with the soil below, and moisture from these lower layers is lost to the air. Accordingly, it is considered necessary to cultivate after showers to prevent the formation of the soil crust. By "summer fallowing" is meant a system of clean cultivation, **without a crop,** which maintains a surface mulch and prevents the growth of weeds. The moisture content of fallow soil is always higher than that of cropped soil. Cultivation is effective in checking evaporation from a soil. Its effectiveness is probably largely due to the destruction of weeds.

It is believed that windbreaks check evaporation from the soil and from plants, through a reduction in air movement. It is well known that a reduction in air movement results in a decrease in the rate of evaporation and transpiration. It has been stated that it may save a considerable percentage of the moisture lost by evaporation, for some distance on the leeward side of the windbreak. Of course, it must be remembered that the trees of a windbreak enter into competition with crop plants, especially annual crops, and take from them sunlight, soil moisture and some soil fertility. However, it is claimed that the zone from which soil water is taken is not as wide as that over which there is a gain through reduction in transpiration.

The use of tents and other cloth covers has been adopted on a large scale in growing tobacco, lettuce and other crops in which a certain leaf texture or succulence is wanted (Fig. 100). One of the effects of shading is to cut down the rate of water loss. The same result is obtained by covering with glass which is coated with whitewash to reduce light intensity.

Increasing the Capacity of the Soil for Water.—By water-holding capacity of a soil is meant the amount of water it can hold

against gravity. For example, take a volume of soil in a container, the bottom of which has holes in it to permit free drainage; slowly keep adding water to this soil until it begins to drip through the holes; now, allow it to stand until the force of gravity has drained as much water from the soil as is possible; the water which is held in the soil represents its water-holding capacity. For example, if we started with 100 pounds of absolutely dry loam soil, and by adding water found that it could retain 30 pounds, then the water-holding capacity would be 30 per cent.

The moisture capacity of a soil is determined by its **texture,** its **structure** and the **amount of organic matter** in it. A soil of fine texture, such as clay, may hold as much as 40 per cent of moisture against gravity, whereas a soil of coarse texture like medium sandy loam will hold only 7 per cent of moisture. The water-holding capacity of a sandy loam with a loose structure is increased by compacting; whereas the clay soil may have its water-holding capacity somewhat increased by loosening.

In general, it is held that the addition of manure or other organic matter increases the water-holding capacity of the soil, but only to the depth that it can be incorporated in the soil.

Decreasing the Water Supply in the Soil.—Too much water may result as disastrously to plants as too little water. A high-water content in the soil means that the air in the soil spaces is replaced by water, and consequently the plant suffers from lack of oxygen. Moreover, carbon dioxide accumulates in a non-aërated soil, and has a poisonous effect upon the roots. It is a belief, which is open to question, that too much water to orchard trees may produce too rapid growth of young trees and induce "bitter pit" or "water core," or an unsatisfactory texture and color of fruit. The water supply may be decreased in such a situation by growing a cover crop.

Where evaporation from the soil surface is rapid, and where the water table is close to the surface, a condition of "alkali" may result. The ground waters are rich in the ordinary mineral nutrients necessary to plant growth, and as the water containing these in solution evaporates, salts are left on the ground. Now, if the water is so close to the surface as to make possible an un-

broken column of capillary water, there is a rapid accumulation of salts on the soil surface, which are popularly known as "**alkalies.**" Much land in the west has been over-irrigated, and this along with natural seepages from canals and lateral ditches has filled up the soil with water, and in many instances the water table is within 4 feet, or even less, from the surface.

In the low-lying lands of the humid sections of the United States and in the over-irrigated, seepage districts of the arid west, drainage is the only remedy for reducing the water supply to a point suitable for plant growth.

The Basis of Drought Resistance in Plants.—Most plants have provisions for regulating water loss. There are considerable differences among plants in the effectiveness of these provisions for preventing excessive transpiration. In other words, there are marked differences in the drought resistance of plants.

Man has combed the earth in search of plants that are economical in the use of water; and he has been seriously engaged in the breeding of drought-resistant plants. In both of these endeavors he has been highly successful. During the hundreds of thousands of years that various forms of plants have been developing on the surface of the earth, they have solved the problem of controlling water loss in various ways. Plants are not confined to the dull monotony of one method in the solution of their water problems.

Let us discuss some of the principal ways by which plants are able to succeed under dry conditions.

1. **A Cuticle.**—The surface of the leaves, stems and other organs of plants is often covered with a layer of cutin, a fatty substance, which is highly impermeable to water (Fig. 88, C). This is called the **cuticle.** The cuticle is a transpiration-reducing structure of high efficiency. For example, the transpiration from a peeled apple for a period of three hours is 20 times that from an apple with the cuticle intact.

2. **Waxy Excretion.**—Some plants excrete a thin coating of wax over the surface. These deposits of wax give to the surface a bluish-gray color, which is called the "bloom." It is particularly noticeable on plum fruit, and on the leaves of carnations,

cabbage and other plants. This bloom may be easily wiped off. Thin as this wax coating of a leaf may be, it is a very efficient agent in decreasing water loss. The mere rubbing of the "bloom" from a leaf may increase the amount of water transpired by one-third. Fruit in storage may be injured by wilting,

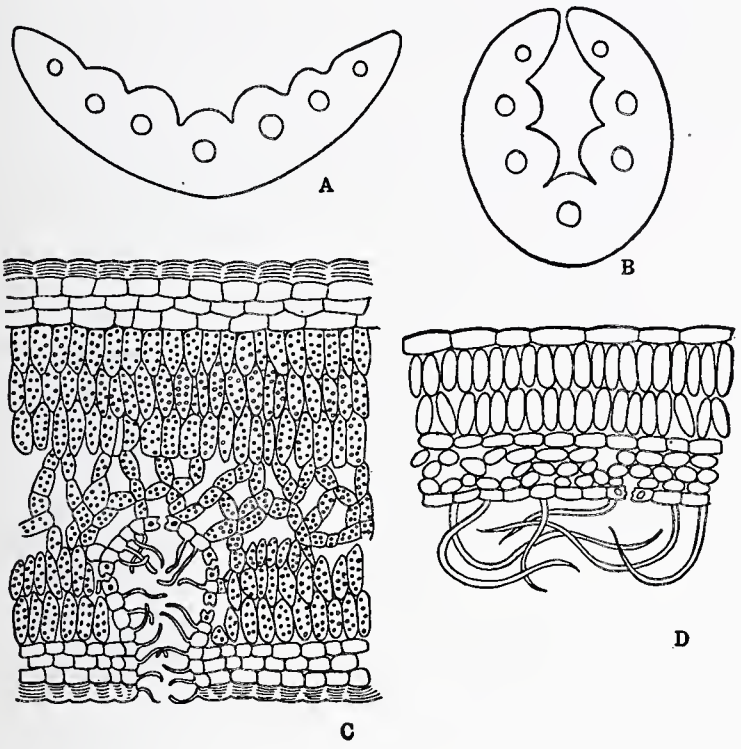

FIG. 88.—Protection from excessive transpiration. *A*, cross-section of an open leaf of fescue grass, filled with water; *B*, the same, after being subjected to loss of water; *C*, cross-section of oleander leaf showing thick cuticle, three-layered epidermis, and stomates deeply imbedded in pit; *D*, cross-section of silver poplar leaf, showing woolly hairs on under surface. (*A* and *B*, redrawn from Kerner and Oliver.)

and it has been shown that fruit picked green wilts more quickly than that which has reached maturity. This is due to the thicker waxy covering of the ripe fruit.

3. **Hairs.**—The surfaces of many plants are often provided with a dense felt-like or scaly covering of hairs (Fig. 88, D). These

hairs, covering the pores, and forming a dead air space immediately above the leaf surface, are of considerable importance in reducing transpiration. Hairy plants are abundant in desert and semi-desert regions, where they often give a characteristic grayish color to the landscape.

4. **Distribution of Stomates.**—It was pointed out that the principal loss of water from a plant was through the pores or small openings (stomates) in the leaf epidermis. In many plants, the stomates are confined to the lower surface of the leaf. Clearly, stomates on the under surface of a leaf will be less likely to endanger the plant by allowing excessive transpiration than would stomates on the upper surface. The temperature of the lower, shaded side of the leaf will be less than that of the upper side, and the air next to the lower surface will not be as dry as that next to the upper side. Again, in many plants growing under dry conditions, the stomates are frequently situated at the bottom of pits or furrows instead of on a level with the general surface of the leaf (Fig. 88, C). These pits or furrows may be lined with hairs, which further prevent water loss.

5. **Leaves that Roll.**—The leaves of many grasses, such as sorghum and corn, possess a structure which enables them to roll up when the atmosphere is dry (Fig. 88, A and B). By rolling up, the transpiring surface is very much reduced, and there is also formed a sheltered space into which the stomates open.

6. **Water Storage.**—Some plants such as cacti, man-of-the-earth, and certain saltworts, endure drought, that is, have the ability to maintain life when the soil is so dry that very little absorption can take place, by the storage of water in their bodies. The plants may live for a long period upon this stored water. Many desert plants have thick, fleshy leaves, or swollen stems and roots, which are efficient water storage organs.

7. **Dormant Organs.**—The ability of many plants to pass through the dry season in a dormant condition is one of the most effective means of withstanding drought. Many trees shed the leaves, their chief transpiring organs, at the onset of a dry season, thus greatly reducing the area exposed to water loss. Some plants die down to the ground as the dry season approaches, and

are tided through this season by underground stems or roots which remain alive. Alfalfa is a splendid example of such a plant. It may be remarked here that the hardy types of alfalfa, such as Grimm and Baltic strains, have a low-spreading form of crown with the numerous buds and shoots coming from below the soil surface; hence, they are better protected from the winter loss of water than are the non-hardy types which have an upright-growing crown with but few buds and shoots developed below the soil surface.

It should be further noted here that in temperate climates the winter season is the " dry " season as far as plants are concerned, for although there may be moisture in the soil, absorption by root hairs is at a standstill because of the low temperature of the soil.

8. **Reduced Water-losing Surface.**—One of the most common drought-resistant characters of plants is the reduction of the transpiration surface. The leaves of many plants, such as pines and spruces, Russian thistle, many grasses, sedges, and others have a very small surface area. And, there are other plants, such as the cactus, which have no foliage leaves at all; here the entire plant body above ground is fleshy stem, and the water-losing surface is reduced to a minimum.

9. **Low Water-requirement.**—Plants vary a great deal in their water-requirement, that is, in the total quantity of water which they expend in producing a unit of dry substances. For example, whereas millet transpires approximately 310 pounds of water for every pound of dry matter produced, sorghum transpires 322 pounds, corn 368 pounds, wheat 513 pounds, oats 597 pounds, potatoes 636 pounds, and alfalfa 831 pounds, for every pound of dry substance produced. Thus it is seen that some plants are more economical than others in the use of water.

10. **Extensive Root System.**—Another factor that enters into drought resistance is the ability of the plant to develop a root system that will utilize to the greatest degree a scanty supply of soil moisture by absorbing water from an unusually large mass of soil.

Many plants, including certain crop plants, which are successful under dry-land conditions have a combination of the adaptations

for resisting drought. For example, the resistance of the sorghums to drought is due largely to their low water-requirement, along with their ability to roll the leaves with approaching dry periods, and thus reduce the water-losing surface, and also to their capacity to remain alive during a period of drought and quickly resume growth when moisture is available.

Agricultural Practices Adapted to Dry Climates.—Many of the agricultural practices in arid and semi-arid regions are such as to conserve water. In these regions, water is the chief limiting factor in crop production and every means is adopted to grow plants so that they will withstand drought. With a shortage of water the crop stand must necessarily be thinner than where water is abundant. Cereals may be induced to stool so heavily by the application of an early moisture supply and fertilizers, that the soil moisture is early exhausted and there is insufficient moisture to insure proper maturity. Weeds take from the soil large quantities of water that should go to crop plants; consequently, it is particularly urgent that weeds in dry land agriculture be kept down. Orchard trees in dry climates may have their transpiring surface reduced by judicious pruning. Dwarf varieties of crop plants are often favorably adapted to arid and semi-arid agriculture. In order to escape the dry period it is the practice to so time the seeding of annuals that their principal growth will be made when soil moisture is available.

CHAPTER XVI

TEMPERATURE AS RELATED TO PLANT LIFE

It is well known that the amount of heat which a plant receives greatly influences its growth. Every process of the plant, including such important functions as respiration, food manufacture, absorption, digestion, and reproduction, is influenced by the temperature.

The grower of plants may ask himself such questions as follows: What are the temperature limits for the growth of a certain plant? How do plants or plant organs differ in their ability to endure low temperatures? What constitutes the practice of "hardening off" plants? What is the cause of sun-scald? Under what conditions are buds, blossoms, fruits and roots killed by low temperatures? How does the soil temperature vary, and what are the factors which cause this variation? What are man's ways of controlling the temperature under which crop plants grow?

Influence of Temperature upon the Distribution of Plants.—The temperature plays a great part in determining the distribution of plants over the surface of the earth. There is a decrease in the temperature as we go from the equator to the poles, and from low to high altitudes. We recognize the broad zones of vegetation peculiar to the tropics, the sub-tropics, the temperate zones and the Arctic regions.

The temperature not only limits the distribution of native plants, but that of crop plants as well. In the United States, for example, cotton is not grown profitably north of the line the average summer temperature of which is below 77° F. (Fig. 89). On the other hand, crops like sugar beets and potatoes do not flourish in the Southern States, when grown during the regular summer season. Rye is seldom grown for grain south of the

mean summer temperature line of 75° F., and the principal centers of production are located where the mean summer temperature is about 70° F.

Very little corn is raised where the average summer temperature is less than 66° F. or where the average night temperature during the three summer months falls below 55° F. "The climatic boundaries of the region of greatest production in the

FIG. 89.—The influence of temperature on the distribution of crop plants. The dark heavy line passes through those points which have an average summer temperature of 77° F. Cotton is not grown profitably north of this line.

United States are a mean summer temperature of 70° F. to 80° F., a mean night temperature exceeding 58° F., a frostless season of over 140 days . . . "

The temperature range of barley in the United States exceeds that of any other cereal. It grows at high altitudes in the Rocky Mountains where the mean summer temperature is as low as 52° F. and in California where it is 95° F. However, the chief barley regions have no month during the growing season which has a mean temperature above 75° F. The commercial apple-

producing regions do not extend south of the line 79° F. mean summer temperature. " The northward distribution ends approximately at the mean winter (December, January, and February) isotherm of 13° . . . ."

Plant Zones.—Vegetation zones or belts corresponding to temperature zones, are well observed in the mountains. In the Central Rocky Mountains, for example, the following vegetation zones are recognized: (1) The plains, a grass-steppe, up to 6000 feet; (2) yellow pine—Douglas fir zone, 6000–8000 feet; (3) lodge-

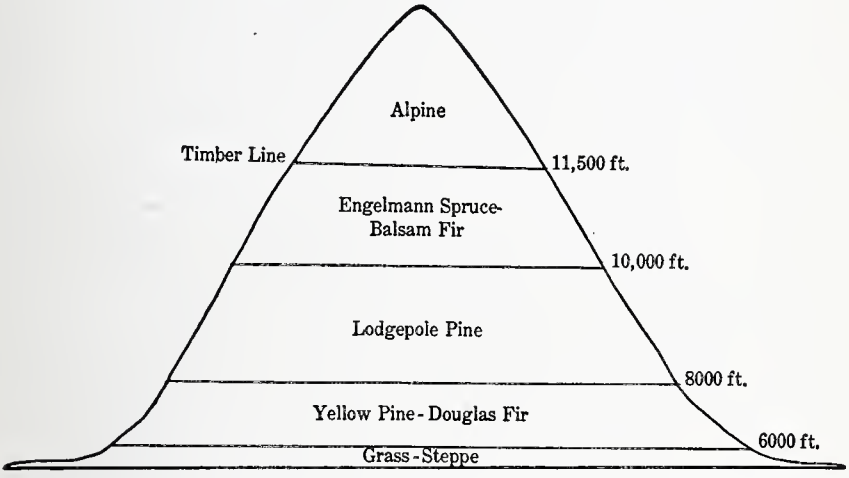

Fig. 90.—Diagram showing plant zones in the central Rocky Mountains.

pole pine zone, 8000–10,000 feet; (4) Engelmann spruce-balsam fir zone, 10,000–11,000 feet; (5) alpine zone, above timber line. Here, too, the crop possibilities in these various temperature zones are different. For example, in the yellow pine belt, it is possible to grow wheat, oats, barley, rye, potatoes, alfalfa, and many of the hardier vegetables; it is not possible to grow to maturity corn, tomatoes, cucumbers, beans and other tender plants.

Growing Plants Outside of their Natural Temperature Range.—Man has moved plants from one part of the world to another. He has endeavored to get them to grow beyond their natural temperature range. His efforts have met with considerable success. It is recognized that varieties from a southern range are

more sensitive to the cold that those from a northern range. If southern-grown seed is planted in a northern climate, it must be grown in a warm soil in order to compensate for the unfavorable climatic conditions. Varieties from a northern range, when planted farther south, are usually earlier in their new surroundings than are southern varieties. This earliness can be overcome in part by planting in a cool soil or on a north slope.

Numerous practical experiments have shown that many varieties of cereals taken from a warm to a cooler climate in a few years shorten their period of growth; they become adjusted to the shorter growing season of the cooler climate. Corn, taken from the Central States to the northern tier of states, has within a few years reduced its lifetime from 123 to 90 days.

It has been asserted that "an annual plant may be said to belong to no country in particular, because it completes its existence during the summer months, and in every part of the world there is a summer." The great agricultural importance of the cereals is mainly due to their annual habit. This means that they may be grown over an extensive area, and a wide range of climates. Cultural methods are adopted to overcome the effects of unfavorable climatic conditions. Strains are secured which are adapted to the different summer climates of the country.

Perennials are unlike annuals in that they are exposed to the climatic conditions not only of the summer, but of the winter as well. They must be capable of withstanding the seasonal variations—the extremes of heat and moisture.

Effect of Temperature upon Growth.—When a plant grows, there is an increase in the number of cells and in the size of the cells. Two new cells result from the division of an old one. The two newly-formed daughter cells, at first small, increase in size. Of course, the growth of the plant body as a whole is the result of the combined growth activity of the many cells which make up the body. Not all cells of a plant at any one time are growing at the same rate; in fact they are not all exposed to the same environmental conditions.

Every plant carries on its life processes between certain temperature limits. There is a certain low temperature below which,

and a certain high temperature above which, a given plant can not grow. We call these temperatures, the **minimum** and the **maximum,** respectively. Somewhere between these two, there is a temperature at which the plant grows to the best advantage. This we call the **optimum.** These three important temperature points are called **cardinal temperatures.**

The following cardinal temperatures are taken from Haberlandt. They will, of course, vary somewhat with the variety.

Cardinal Temperatures for Growth, Degrees Fahrenheit

	Minimum	Optimum	Maximum
Oats	32–40	77–87	87–98
Rye	32–40	77–87	87–98
Wheat	32–40	77–87	87–98
Barley	32–40	77–87	87–98
Pea	32–40	77–87	87–98
Corn	40–51	98–111	111–122
Pumpkin	40–51	98–111	111–122
Cucumber	51–60	87–98	111–122
Melon	51–60	87–98	111–122

The cardinal temperatures for the different functions in the same plants are not the same. For example, a wheat seed will germinate and "stool" at a few degrees above freezing, but flowering and fruiting take place only at much higher temperatures. Again, it is known that the germination temperature influences the development of the adventitious roots in wheat. In this plant, the first whorl of adventitious roots forms much nearer the soil surface at high temperatures than it does at low temperatures. The plants in the former case are relatively weak. Seedlings of wheat, germinated at temperatures just above freezing, develop a root system two to three times as large as those grown at higher soil temperatures.

Resistance of Plants to Low Temperatures.—It is well known that some plants will withstand a much lower temperature than

others. For example, the date palm is usually injured by temperatures below 20° F., whereas most varieties of apples will endure temperatures much below zero, if the tissues are mature and in a dormant condition. It is also recognized that different tissues of the same plant vary in their resistance to low temperatures. In our common woody plants, the tissue least resistant to freezing is the pith; the next least resistant is the sapwood, then the bark, and the most resistant, in well-matured and well-hardened stems, is the cambium. However, in actively-growing stems, the cambium is not so resistant to freezing as other tissues.

There are certain conditions which influence the degree of injury at any particular low temperature. For example, it is known that with dormant tissues, a **rapid lowering** of the temperature to a certain degree is more injurious than a **slow decrease** to the same temperature. But, contrary to the common opinion, the rate at which thawing takes place has little to do with the injury from exposure to low temperatures; and, too, there is little evidence that direct sunlight has an injurious effect on frozen tissues.

The more water plant tissues contain, the more readily are they killed by freezing. Active, growing tissues have more water than dormant tissues, and consequently are more easily frozen to death. Seeds that are well dried will stand much lower temperatures than ones filled with moisture. For example, corn often suffers from freezing before the grain is thoroughly dry. If the grain becomes thoroughly dried, it will withstand very low temperatures. Corn containing 10 to 14 per cent moisture may be stored with safety in bins exposed to temperatures considerably below 0° F. A frozen grain of corn may have the appearance of being healthy, but the germ (embryo) may be killed or its vitality considerably reduced. It is very essential that corn seed be given a careful test for germination before planting.

The maturing or "hardening" of plant tissues that takes place in late summer, autumn or early winter seems to influence the resistance to winter temperatures. Well-matured or hardened tissues are more resistant than those not completely matured or hardened. For example, wood that has had late growth and

gone into the winter incompletely matured is comparatively susceptible to winter injury.

Gardeners commonly practice the process of " hardening off " their transplants. If a tomato plant is removed suddenly from a warm greenhouse in the spring to the garden out-of-doors, it has little resistance to low temperatures, and the death-point is relatively high. The usual procedure is to move the plants from the greenhouse to a cold frame where the temperature extremes are not so great as in the open; here the plants become adjusted to the lower temperatures and after a period may be planted with safety in the open. After the " hardening-off " process, the plant is able finally to withstand a lower temperature than if suddenly removed from a warm to a cool situation. " Hardened " plants differ from tender plants in having in the cells more soluble proteins and more water-imbibing substances.

Temperature conditions preceding and leading up to a cold period are important in influencing the resisting power of a plant. A series of warm days preceding a " cold spell," which permits the formation of many new plant cells, with their thin walls, a scarcity of water-holding substances and an abundance of free water, is especially injurious.

Winter-killing.—Fruit trees, winter wheat, and such perennials as alfalfa, strawberries, and clover, are known to winter-kill. In the freezing of plant tissues, water is withdrawn from the cell, and the crystals of ice form in the intercellular spaces. After thawing, the tissue has a water-soaked appearance. It is known that many plants may survive extremely cold weather provided it is not accompanied by a dry atmosphere. It appears that winter-killing under certain conditions in the arid and semi-arid parts of the West results from lack of water. The dry winters, accompanied by sunshiny days, high winds, and a low rate of absorption from the cold soil, result in a lack of water to the shoots, and death of the tissue results. Winter damage to wheat may be due to heaving of the soil, and to smothering, as well as to drought, and to the direct effect of low temperature. Heaving is due to the alternate freezing and thawing of the soil, which lifts the plant from the soil and exposes the roots to the air.

Smothering may occur when the soil is coated with an ice-sheet.

Sun-scald.—This is a name frequently given to a type of winter injury which occurs usually on the south or southwest sides of the trunk or larger branches of trees. The side of a trunk or branch exposed to the sun may become many degrees warmer during the afternoon than the opposite side. If this period of heating is quickly followed by freezing temperatures, injury is likely to result; the cambium is destroyed, and the bark may finally loosen and fall off. Sun-scald may be avoided by shading the trunk or branches, and thus prevent their heating. This is accomplished by wrapping them with straw or burlaping, or by placing a board or lath screen along the southwest side. The whitewashing of trees may also have a tendency to prevent sun-scald. The white coating reflects the heat to a greater extent than the darker colored bark. Sun-scald may also result from excessive summer heat, as not infrequently occurs in California.

Splitting of the Trunk.—The trunk of a tree may split open in severe freezing weather, and remain open until spring. The frost cracks may close in the summer and heal over. It is believed that this splitting is due to the withdrawal of water, in freezing, from the cells into the spaces between the cells, with the resulting shrinkage of the tissues.

Killing of Buds.—As a rule, vegetative buds, that is, leaf or stem buds, are more resistant to low temperatures than flower (fruit) buds. Bud scales protect the enclosed parts from drying out, but they do not keep these parts "warm." Temperatures on the inside of a bud may be as low as on the outside.

As buds begin to open, their resistance to freezing decreases. Not commonly, a number of warm days in early spring may incite the buds to begin growth. Such buds are less resistant to low temperatures than fully dormant ones. Consequently, if these few warm days are followed by low temperatures, the buds are injured.

Killing of Blossoms and Fruit.—As a rule, open flowers and fruits will not withstand as low temperatures as the buds. In

the open flower, the pistil seems to be the most tender, and in young fruit, the seeds are less resistant than other tissues.

Killing of Roots.—The roots of trees are much more tender than the tissues above ground. However, soil temperatures seldom are as low as air temperatures. It is only under severe temperatures or when there is a lack of snow or other protective covering on the soil that root-killing occurs. In cultivated orchards, a cover crop which holds a snow blanket, is recommended to prevent root-killing.

Soil Temperature.—Soil is the medium in which the seeds of crop plants germinate. Moreover, the roots, which have the highly important function of absorption, grow in the soil and are surrounded by it during all their life. And, too, the many organisms of the soil, the activities of which have so much to do with its fertility, are very greatly influenced by the soil temperature.

The soil temperature is by no means always the same as the temperature of the air above it. It may be lower or higher than the air temperature. There are numerous factors affecting the temperature of a soil; chief of these are as follows:

1. *Air Temperatures.*—Changes in the air temperature above a soil result in changes of the soil temperature. The fluctuations near the surface are almost parallel to those of the air, but at deeper layers the variations correspond to a lesser degree. The daily temperature change in bare, fallow soil extends to between 12 and 24 inches from the surface.

2. *Exposure.*—By exposure is meant direction of slope. A north exposure, for example, faces north. The effect of exposure at high altitudes is much more marked than at low elevations. This greater effect is a direct result of the increased rate of radiation at high altitudes. The intensity of sunlight is distinctly affected by exposure and also by degree of slope. A given area of soil or plant surface that is at right angles to the direction of the rays of light will receive much more heat than one upon which the sun's rays fall obliquely, for under the latter condition the rays are spread out over a larger area than when they fall perpendicularly (Fig. 91). If we assume the intensity of sunlight to be 100 when it strikes a surface at right angles, its intensity

when striking that surface at an angle of 70° will be approximately 98.5; at an angle of 60°, 96.5; and at an angle of 10°, 33.4. Light intensity has its effect upon both air and surface temperatures, which indirectly affect the amount of moisture in the soil, and the relative humidity over the soil. The differences between the native vegetation on adjacent north and south exposures is so conspicuous in the mountainous sections as to attract the attention of the most inobservant person. In a valley that trends east and west the slope exposed to the south has a much greater total effective heat during the year than the northerly exposure across the valley. The greater light intensity on the south exposure not only results in a warmer, but a drier, habitat than occurs on the neighboring north exposure. A south exposure receives the greatest total heat during the day, the east the next greatest, then the west, and the north exposure least of all.

3. *Living Cover.*—A crop shades the ground and prevents the soil from warming up. A bare soil warms up more quickly, and cools off more rapidly than one covered with vegetation.

4. *Non-living Cover.*—(Snow and mulch.) It is well known that a snow covering prevents rapid changes in the temperature of the soil. The temperature of soil under snow is higher than that of soil unprotected. Boujoucos found on a cold January day the following conditions, at 3 inches deep:

	Daily Average Temp. Deg. F.	Min. Temp. Deg. F.
1. Bare soil	16.27	7.50
2. Covered with compacted snow	18.37	15.60
3. Covered with uncompacted snow	27.90	27.00
4. Covered with a layer of vegetation and uncompacted snow	32.60	32.20

The temperature of a cultivated soil fluctuates to a less degree than that of an uncultivated soil. This is probably due to the

poor heat-conducting power of the mulch formed on the surface of the cultivated soil.

A non-living vegetative cover, such as a straw mulch, prevents rapid changes in the soil temperature. It has a cooling effect in the summer, and a warming effect in the winter. In the winter, the dead vegetative covering acts as a poor heat-conducting medium, which prevents a rapid loss of heat from the soil; and it tends to keep the cold air currents from coming in contact with the soil. It is a common practice to place straw mulches over such low-growing plants as strawberries.

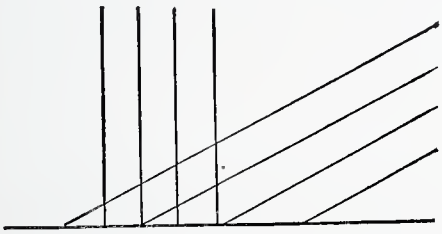

FIG. 91.—Diagram showing the relation between the angle at which the rays of light strike the surface and the amount of heat which the surface receives. The distance between the perpendicular lines is the same as that between the oblique lines, and this distance represents a ray of light. Observe how the oblique light is spread over a much greater area than that which is perpendicular.

5. *Moisture.*—A wet soil is usually a cool soil, whereas a dry soil is usually a warm soil. Some of the heat absorbed by a soil is used in evaporating the water in it. A wet soil will absorb more heat than a dry one. Even a light shower will lower the temperature of the surface soil to a considerable degree. It not only directly cools the soil by its addition, but, as stated, evaporation also lowers the temperature.

6. *Color.*—Dark soils absorb heat more readily than light-colored ones, and consequently heat up more rapidly.

7. *Physical Nature of the Soil.*—A coarse soil does not retain water readily, consequently it warms up rapidly. On the other hand, a fine-grained soil, like clay or loam, holds water well and as a result warms up slowly. It is customary to speak of the former

as " warm or early soils," and of the fine-grained soils as " cold or late soils." Soils that are compact conduct heat more rapidly than loose ones. This means that a compact soil will heat up quickly and just as readily cool off.

8. *Manures.*—The general effect of applying manures to a soil is to raise its temperature. In one experiment it was noted that 20 tons of manure applied to an acre increased its soil temperature 5° F.

Man's Control of the Temperature Relation.—Man may increase the temperature of the air about plants by the use of

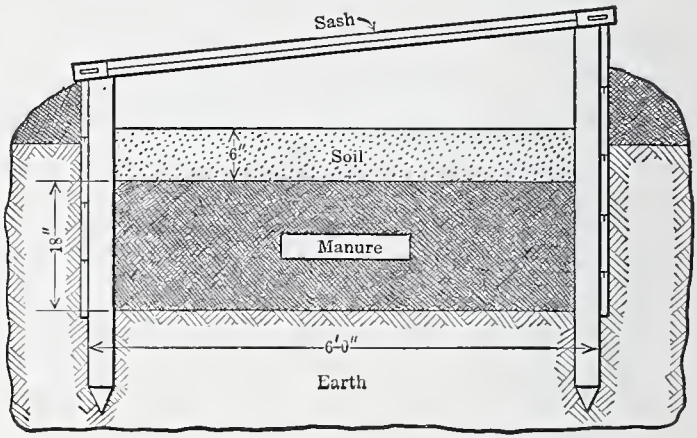

FIG. 92.—A permanent hot bed. (Redrawn from Nissley, in New Jersey Agr. Exp. Station Bulletin.)

(1) hot-houses (greenhouses), (2) hotbeds, (3) cold-frames, (4) fires and smudge pots in orchard heating, and (5) by cultural practices.

The modern greenhouse is used for growing all sorts of plants from many parts of the world for the benefit and pleasure of man. In the large conservatories of the cities one may step from a zero temperature outside into houses where tropical palms, bamboo, orchids and scores of other plants requiring high temperatures are growing luxuriantly. Greenhouses are used commercially in growing ornamental plants for winter use, and also to force vegetables. Many vegetables, chiefly lettuce, tomatoes, cucum-

bers, radishes, cauliflower and beans are "forced" on a large scale. The "forcing" industry is confined to the immediate vicinity of large cities where there is a ready demand for vegetables out of season.

The hotbed is a familiar forcing structure, in which the heat is raised by fermenting manure (Fig. 92). Some plants like radishes and lettuce may be brought to marketable size in the

FIG. 93.—Temporary cold frame. Hardening off potted tomato plants for early field planting. (From Nissley, in New Jersey Agr. Exp. Station Bulletin.)

hotbed. In the northern states where the seasons are short, long-season crops, such as tomatoes, cauliflower, peppers, etc., are started in the hotbed, cold frame or greenhouse, and transplanted to the open when seasonal conditions permit.

Cold frames are covered with glass-sash or muslin, and have no heat except that which they receive from the sun. The plants within receive some protection from frost. Plants are often "hardened off" in cold frames. Transplants from the hothouse are removed first to cold frames before setting them in the open.

In the fruit belts of the Rocky Mountains and Pacific Coast, orchard heating has long been practiced with varying degrees of success. Some of the largest fruit districts of these areas are subject to late freezes in the early part of the growing season. Various ways of raising the temperature of orchards have been used.

1. *Smudging.*—The object of this is to create a dense smoke which is allowed to float over the orchard. The smoke cloud

Fig. 94.—Lettuce as an intercrop in a cucumber house. (From Beattie, in U. S. Dept. Agr. Farmers' Bulletin No. 1320.)

may prevent somewhat the radiation of heat from the soil, which heat was absorbed by the earth during the day. Further, considerable water vapor is given off by the burning smudge, and this will help to hold the heat. The smudge is secured in a number of ways: (1) by drawing through the orchard a wagon carrying wet burning straw; (2) by burning piles of damp straw, sacks of manure, bales of wet excelsior or crude petroleum coal, placed in wire baskets.

2. *Heating.*—Smudging has been quite generally replaced by the use of coal and oil in especially designed heaters. No attempt is made to create a blanket of smoke and vapor; the air temperature is actually elevated by numerous burning fires well distributed in the orchard. Results of investigations carried on at a number of different experiment stations show that with 100 heaters to an acre, an orchard will remain about 4° F. warmer than the surrounding unheated area. This is sufficient to save a crop in many instances. The best results are obtained on still nights. A wind may destroy entirely the effects of heating. Orchard heating is an expensive procedure, and in many cases, the fruit saved no more than equals the cost of saving it. On the other hand, it has resulted in tremendous savings.

As has been stated, the grower recognizes two types of soil as to their temperatures:

(1) **"Warm or early soils,"** and (2) **" cold or late soils."** A " warm soil " is one of coarse texture which retains a comparatively small amount of water. A " cold " soil is one of fine texture which holds a relatively large amount of water. It requires more heat to raise the temperature of a given body of wet soil to a certain number of degrees than it does that of the same body of dry soil the same number of degrees. Heavy soils such as clay which retain much water, warm up much more slowly in the spring than do light, sandy soils. Consequently, the heavy, wet soils are " late " and the light, sandy soils are " early." Crops make an earlier start and come to maturity sooner on warm or early soils than on cold or late soils. Of course, there is a disadvantage to warm soils in that they dry out easily.

There are several ways of raising the temperature of a " cold or late soil." For example, the temperature of a soil may be raised in the spring by (1) draining; (2) adding a dark-colored humus or manure; (3) compacting the surface of the cultivated soil, and (4) covering the soil surface with a thin sand layer.

The winter soil temperature may be raised by covering the soil with a mulch of straw, or dead vegetation.

The temperature about plants may be decreased by the use

of (1) cold-houses, (2) shading, and (3) cultural practices which lower the soil temperature, such as irrigation, and cultivation which tends to make the soil texture finer. In the summer, plants in greenhouses are kept cool by covering the glass with frames of lath, or by "painting" the glass with lime.

The Rest Period.—There is a normal period in the life of deciduous plants known as the **rest period**, during which they are in a condition of rest, that is, will not grow even when temperature and moisture conditions are favorable. During this period, the tissues are in a state such that they are able to endure extremes of temperature and dryness. Deciduous fruit trees gradually go into the period of rest soon after length growth of twigs has ceased in late summer or autumn. During this period, growth is at a stand-still, although, of course, there is not a complete stopping of plant activities.

It seems that the beginning of the rest period is hastened by conditions which are unfavorable for growth, such as a deficiency of water or nitrogen. The ending of the rest period is also a gradual process. This is illustrated in the case cited by Chandler, as follows: "In the climate of Missouri, if peach twigs are taken from the tree in November or early December and the ends placed in water in a warm room, the buds will not grow; but if they are taken in late December or early January, they will grow slowly; while if they are taken in February, they will grow much more rapidly." In this case, it will be noted that in November and early December, the twigs are in the rest period; in late December or early January the rest period is breaking; and, in February, the rest period is almost entirely broken.

The rest period of twigs may be broken by various treatments: etherization; exposure to smoke, to acetylene gas, to Roentgen rays; immersion in water at a temperature of 70° to 100° F., and in weak solutions of a number of different salts; wounding, etc. Prolonged exposure to low temperature is nature's method of breaking the rest period. In the coast and valley sections of California, the winters are too mild to fully break the rest and as a result there is some delay in the spring opening of the buds, even though the temperatures are not too low for slow opening

of the buds. This delay has its advantages, chief of which is a lessening of the frost hazard.

A rest period is not peculiar to the stem tissue of deciduous trees. Many seeds, as discussed on pages 108 and 109, exhibit a dormancy or rest period. Also, tubers of potatoes, bulbs of tulip, narcissus, crocus, and other plants, and the underground stems, and roots of other plants exhibit a rest period. The etherization of bulbs as a forcing measure is commercially employed.

CHAPTER XVII

LIGHT AS RELATED TO PLANT LIFE

In growing plants, we are forced to consider the influence which light exerts upon their behavior. Light affects the movement and position of plant organs, and the size, form and structure of plants; the amount of food manufactured by plants depends upon the duration and intensity of light; and whether a plant flowers and fruits or not appears to be determined by the relative length of day and night. Moreover, such commercial practices as " blanching " and " forcing," involve a knowledge of the effect of light upon plants. It is well known that the development of a green color and the manufacture of sugar (photosynthesis) in plants go on only in the light.

Light Energy Changed to Heat Energy.—Much of the light energy which comes to a plant is transformed to heat energy. The temperature has its effect upon the different functions of the leaf, such as water loss, food manufacture, and respiration. As we have seen, each of these functions of the plants has certain cardinal temperatures. For example, let us consider a leaf carrying on the function of food manufacture. There is a certain **minimum temperature** below which this process ceases; as the sun's rays increase the temperature of the leaf, the rate of food manufacture increases until it reaches a maximum at the so-called **optimum temperature;** then, if the temperature goes above the optimum, the rate of activity decreases until the **maximum temperature** is attained above which the function ceases altogether.

The Movement and Position of Plant Organs are Influenced by Light.—The direction of light and its intensity have an effect upon the movement and position of plant organs. Plants in the

FIG. 95.—Two halves from the same dandelion plant, one (right) grown at high altitude in the mountains, the other (left) in fertile soil at low altitude. (From Jones, in *Genetics in Plant and Animal Improvement;* after Bonnier.)

window grow towards the light. Leaves are especially sensitive to light. Many leaves assume a position which will expose a flat surface to the direct rays of light. On the other hand, under conditions of intense and excessive illumination, the leaves of some plants, such as wild lettuce, take a position which exposes their edges to the sun during the hottest part of the day.

Fig. 96.—Effect of light on plant growth. (*a*) Peas grown in darkness; (*b*) in about one-fifth light; (*c*) and open in greenhouse. (From Duggar, in *Plant Physiology*.)

The Size, Form and Structure of Plants are Influenced by Light.—Intense light seems to have a stunting effect. This is shown by the low stature of alpine plants (Fig. 95), although other factors, chiefly low temperatures, and excessive transpiration may play a part. Plants in the dark grow long and spindling, which tendency is noticeable, but less so, in the shade (Fig. 96). There is a marked difference between sun and shade plants of the same species. Trees in the open, branch and spread profusely, whereas the same species in the forest where the light on all sides is cut off, grows taller and produces fewer side branches. The leaves of shade plants are thinner and broader than those of sun individuals (Fig. 97).

As has been stated, in the total absence of light, plants do not develop chlorophyll. The leaves of shade plants, however, are

often a deeper green than those of sun plants. This is due to the fact that the epidermal layer of shade plants is thinner than that of sun plants, and consequently the underlying green tissue of the shade leaf shows through. Moreover, sun leaves are frequently covered with hairs, scales or a waxy coat which prevent the

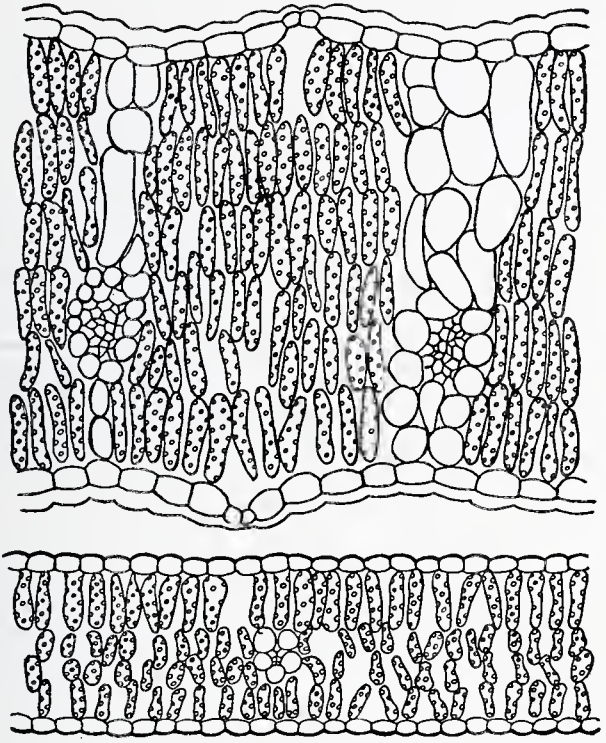

Fig. 97.—Cross-section of a sun leaf (above) and a shade leaf (below) of the same species—a native sunflower. (Redrawn from Clements, in *Research Methods in Ecology.*)

chlorophyll tissue beneath showing through. Such plants often have a grayish color.

Duration of Light.—In a discussion of light and its influence upon plant growth, we must take into consideration its **duration,** its **intensity,** and its **quality.** In the arctic regions the summers have long days, but the light intensity is low; at the equator, the daylight period is shorter, but the light is very intense.

The long daily period of sunlight at high latitudes, even though the light is of low intensity, makes possible the maturing of splendid grain and vegetable crops. It has been found that the accu-

FIG. 98.—Maryland Mammoth tobacco. *A*, the plant at left was grown in the greenhouse in winter, and it shows the behavior when propagated under a short day length. The plant at the right was grown under exactly the same conditions except that the daylight period was lengthened by the use of electric light, and flowering thus prevented. *B*, a crop of Maryland Mammoth tobacco. The plant does not mature seed normally under the influence of long summer days. The seed may be obtained by growing the plants in Southern Florida in winter, thus exposing them to short days. (From Garner and Allard in *U. S. Dept. Agr. Yearbook.*)

mulation of carbohydrates in plants, and their rate of growth, are in proportion to the number of hours the plant is exposed to the light, rather than to the intensity of light.

Relative Length of Day and Night.—It has been found that the relative length of day and night is important in determining the flowering and fruiting of plants. For example, some plants which flower only during the long days of June can be made to bloom in mid-winter, if the length of daily illumination is increased by means of electric lights (Fig. 98). Other plants which normally bloom and fruit in the autumn when the days are short, can be made to bloom and fruit in mid-summer, if the length of day is shortened by placing them a part of each day in the dark (Fig. 99).

Light Intensity.–Plants vary greatly as to the intensity of light which they can withstand. It appears that most plants do best in diffuse light; that high light intensity is injurious in that it destroys the chlorophyll and thus retards the food manufacturing process. It is known that many plants, especially in the seedling stage, can not withstand direct sunlight for any considerable period. In full sunlight, the date palm leaf ceases to grow. Normal growth of this organ is made chiefly in the time between sunset and sunrise, but also to a slight extent in daylight when direct sunlight is cut off by clouds.

It has been found by experiment that the Norway maple is capable of carrying on the manufacture of sugar when the light intensity is only $\frac{1}{55}$ of the total daylight, whereas cherry is incapable of performing this function if the intensity falls below $\frac{1}{3}$ of the total daylight. In other words, Norway maple has the ability to endure shade.

If a plant is grown under conditions in which light is insufficient, it shows certain distinctive characters. For example, the color of the foliage is pale green, and often sickly, the number of leaves is decreased, there is a scanty development of roots, the growth is more succulent, that is, less woody tissue is developed, the stems are long and spindling, and the plant may fail to bloom and produce fruit. If nursery trees are planted too close, such that there is not sufficient light, they tend to grow

FIG. 99.—Biloxi soybeans. Plants in box on left were exposed to the light for five hours daily. Those in the box on the right were kept out of doors throughout the experiment. On August 15th, when the plants were photographed, the plants on left had blossomed and matured seed pods, whereas those on the right had not blossomed. (From Garner and Allard, in *Jour. of Agricultural Research.*)

long and slender, and to have a weak root system. It must be remembered that the vigor of a root system depends primarily upon the food brought to it from the leaves. A decrease of the leaf surface brought about by too close planting is equivalent to a decrease in the food-manufacturing surface.

Sometimes advantage is taken of the response of the plant to decreased light brought on by close planting. For example, flax grown for fiber is planted in a closer stand than when grown

FIG. 100.—Growing Sumatra tobacco under cloth tent, Connecticut Valley, in order to decrease light intensity and improve texture of the leaf. (From Duggar, in *Plant Physiology;* after Shamel.)

for seed. The close stand induces the development of long, slender stems, which yield fiber of high quality. Also, in growing sorghums and corn for fodder, or for ensilage, where a large amount of succulent growth is desired, the plants are grown close together.

In experiments to determine the effects of artificial shading on plant growth in Louisiana, it was found that when the light was decreased to from $\frac{1}{2}$ to $\frac{1}{7}$ of normal illumination, potato, cotton, lettuce and radish plants made greater growth. Tobacco plants are often grown in the shade of tents, which condition makes a larger and thinner leaf with less vascular tissue. The leaf is thus improved for wrapper purposes (Fig. 100).

In general, light of medium intensity promotes vegetative growth, whereas intense light favors the development of reproductive structures. It is known that in the northeastern states, where there are many cloudy days during the growing season, there are splendid yields of such crops as potatoes, carrots, turnips and

FIG. 101.—Throwing soil about the base of celery plants to exclude the light and cause blanching. (From Division of Truck Crops, College of Agriculture, University of California.)

others which are grown for their vegetative structures. On the other hand, the principal seed-producing regions are found in the western and middlewestern states where the percentage of sunshine during the year is high, and the light intensity is relatively great.

Blanching is a process in which the plant is prevented from becoming green by growing it in the dark. To produce blanched (white) asparagus, for example, the plants are banked or ridged up with soil, so that the "spears" must make an additional growth of 4 to 10 inches before they come to light. The shoots that develop in

the soil are, of course, whitish. The blanching of celery is accomplished by placing boards, paper or earth about the stalks to exclude light (Fig. 101). The heads of cauliflower are blanched by bringing the outer leaves up over the head and tying them, thus excluding light (Fig. 102).

The intensity of light to which a plant is exposed may be increased by pruning, and by a thin stand. One of the objects in pruning trees is to allow light into the center of the tree.

The use of artificial light to supplement natural daylight and

Fig. 102.—Blanching cauliflower. The leaves are tied over the maturing "head" to exclude the light. (From Division of Truck Crops, College of Agriculture, University of California.)

thus bring about the forcing of plants has been the object of much experimentation. By keeping such vegetables as lettuce and radishes in the light of a strong arc light during a part of the night, they have become ready for the market from 10 to 14 days earlier than those exposed to normal light duration. Other kinds of artificial light besides the arc light have been used in forcing plants. Among such are the ordinary carbon incandescent electric light, acetylene and Welsbach burner. Although artificial light is effective in forcing certain vegetables and flowers, the practice is not usually attended with commercial gain, on account of the cost of the light.

The Quality of Light.—The white light that shines upon the leaf is composed of a number of different rays, which vary in their effect upon plant growth. The visible spectrum, so beautifully shown in the rainbow, is composed of red, orange, yellow, green, blue and violet light. Beyond the visible red are invisible rays known as infra-red; and beyond the visible violet, are rays of light invisible to the eye, known as ultra-violet. It has been demonstrated that the red rays of light are the most effective in sugar manufacture, and that the green, blue and violet rays are the least useful of all in this process. Ultra-violet rays of light have an injurious effect upon plants, and the rays beyond the violet, of shorter wave length, are extremely harmful to them.

CHAPTER XVIII

THE NUTRIENT RELATIONS OF PLANTS

We have discussed here and there in preceding chapters certain points having to do with plant nutrition. It is our purpose, in this chapter, to summarize these, and to add other important matter bearing upon the nutrient relations of plants.

The two groups of plants based upon their nutrient relations are often spoken of as **independent** and **dependent** plants. All chlorophyll-bearing plants are **independent,** by which we mean, they are able to make their own **food** out of the **raw materials** which they draw from the soil and air. Non-chlorophyll-bearing plants, such as mushrooms, mildews, rusts, smuts, and bacteria, are not able to make their own food but must get it already prepared for them; consequently such plants are **dependent.**

We have mentioned in Chapter V the chemical substances which go to make up the plant. Plants may be analyzed chemically to ascertain their composition. In the first place we find that a very great part of the plant is **water.** The water from a plant or any part of it, may be driven off by heating the substance to a temperature of 105° to 110° C. for several hours. The water content of various plant parts is given on page 169. The water-free substance left after heating is the **dry matter.** If we examine further the dry matter, we find it to be composed chiefly of **carbohydrates,** such as starch and sugars, of **proteins,** of **fats** and **oils,** and of **minerals.** The carbohydrates, proteins, fats and oils are **organic compounds,** whereas the minerals are **inorganic compounds.** Now, if the **dry matter** is heated for a considerable period to a very high temperature, the organic materials are burned and converted into substances which escape from the plant. Consequently, after burning, the non-combusti-

ble inorganic (mineral) matter is left. This is called the **ash.** The chief chemical elements found in the ash are **sulphur, potassium, calcium, magnesium, iron** and **phosphorus.** In addition to these may be found varying amounts of chlorine, iodine, silicon, barium, manganese, aluminum, and many other elements. The ash of plants is usually but 1 or 2 per cent of the total weight.

As stated in a preceding chapter, it has been found by careful experiments that there are ten chemical elements, all of which are absolutely necessary for the normal development of all green plants. These ten essential elements are **carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium,** and **iron.** If plants are grown in water to which all these elements, except any one, are added, they fail to develop in a normal manner.

We have also learned the sources of the essential elements for independent plants. Green plants growing in the soil obtain from the **air:** carbon and oxygen; and from the **soil: hydrogen** and **oxygen,** as water, **nitrogen** (directly), **sulphur, phosphorus, potassium, calcium, magnesium** and **iron.** The other non-essential elements come from the soil.

It was pointed out that **carbon** enters the green plant as **carbon dioxide** from the air. It comes in chiefly through the stomates of the leaves. Oxygen as such enters the plant as a gas, or in the many compounds of which oxygen is a component. Hydrogen is obtained from water. The other elements enter as **salts from the soil.** Thus it is seen that the green or independent plant derives its nutrients from three different groups of substances: **water, carbon dioxide,** and **inorganic salts.**

It will be recalled that water, carbon dioxide and inorganic salts are the raw materials out of which the plant makes its **foods.** These foods are just the same kind as those used by animals and non-green plants to nourish their bodies. They are **carbohydrates** (chiefly sugars and starches), **fats,** and **proteins.** These three groups of substances are the materials used by the plant to construct its body. They are made from the **raw materials** taken from the air and soil.

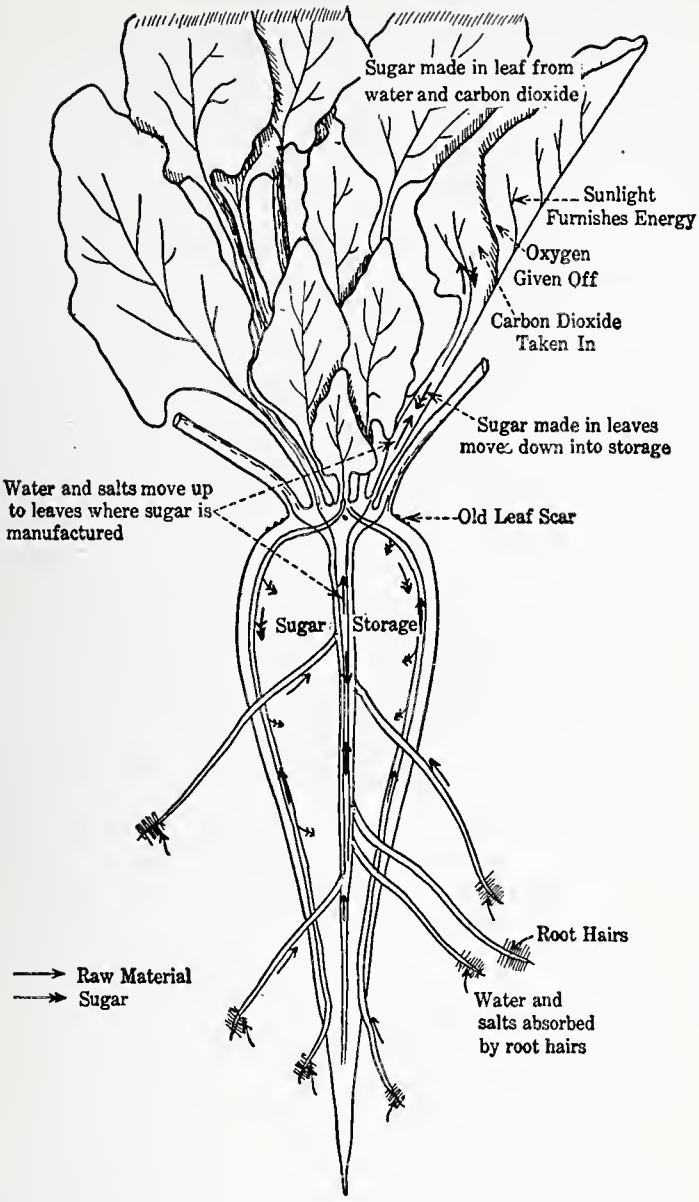
Sugar made in leaf from water and carbon dioxide
Sunlight Furnishes Energy
Oxygen Given Off
Carbon Dioxide Taken In
Sugar made in leaves moves down into storage
Water and salts move up to leaves where sugar is manufactured
Old Leaf Scar
Sugar
Storage
Root Hairs
Raw Material
Sugar
Water and salts absorbed by root hairs

FIG. 103.—Diagram of a lengthwise section of a sugar beet plant showing certain nutrient relations.

As has been stated, only green plants have the power of making their own **foods** (carbohydrates, fats, and proteins), from the **raw materials** (water, carbon dioxide and salts). The process of manufacture is a chemical one and not at all simple. In the first place, the **carbon dioxide** from the air, entering the leaf through the stomates, is chemically united with **water** from the soil, entering the plant through root hairs, and the result is **sugar,** a carbohydrate. This chemical union takes place in the cells containing chlorophyll, and only in the presence of light. During the day carbohydrates usually accumulate in the leaf cells.

It is well for the student to recall at this point that a carbohydrate like sugar or starch, is chemically the simplest food. It contains but three elements, carbon, hydrogen and oxygen. Moreover, it is the foundation of all the more complex foods.

Coming from the soil through the root hairs are a number of salts in solution. These salt solutions pass up through the conducting tubes of the root and stem and out through the leaf stalk and veins into the leaf cells. These salts carry nitrogen, phosphorus, iron, magnesium, sulphur, potassium, and other elements. These elements are chemically united with the carbohydrate already formed in the leaf cells, and more complex plant foods such as **proteins** result.

The **raw materials** of green plants are water, carbon dioxide and mineral salts. They are all **inorganic** chemical compounds. The chief **foods** constructed from these raw materials are carbohydrates, fats, and proteins. They are **organic** chemical compounds. Only green plants are capable of manufacturing their foods from inorganic chemical compounds.

Assimilation.—After a green plant has manufactured carbohydrates, fats and proteins from raw materials, these substances are still in a non-living state. The change of non-living substances to living material is called **assimilation.** The nature of the change is little understood, and it is one of the most wonderful processes in the whole plant.

Digestion and Translocation.—We have just said that during the daylight the green tissue of a plant is manufacturing sugar from carbon dioxide and water. Now, if we examine a leaf

chemically after it has been carrying on this process for a while, we find in it **starch** as well as **sugar.** Moreover, starch will accumulate in the leaf cells during the day. Further examination of the materials that are passing out of the leaf through the leaf stalk shows these to be mainly **sugar** and simple organic nitrogenous substances. Consequently, if starch accumulates in the leaf in the day, it means that sugar is not being moved away from the leaf during the day as rapidly as it is manufactured, and that it is usually changed to another chemical form — starch — and stored as such, at least temporarily. If we examine a leaf early in the morning before light has come to it, we find it contains no starch, whereas the evening before it had an abundance. Evidently, the starch has moved out of the leaf during the night. But, starch occurs in the form of grains (Fig. 104), and these bodies can not pass through the cell walls and get into the conducting tissue. Moreover, starch is insoluble in water. It does not dissolve in cell sap. Before it can pass from one cell to another, it must be changed into a substance which is soluble in the cell sap. Study has shown that the starch is changed to sugar, and sugar, being readily soluble in the cell sap, can pass from cell to cell through the walls and membranes.

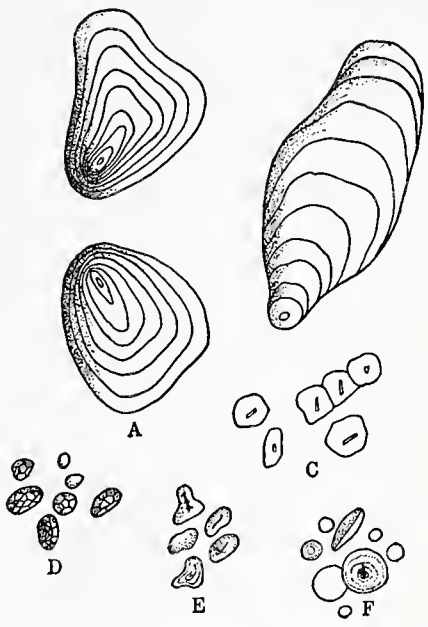

FIG. 104.—Starch grains from different sources. *A*, from the tuber of Irish potato; *B*, from the rootstock of canna; *C*, from the endosperm of corn; *D*, from the endosperm of rice; *E*, from the cotyledons of common bean; *F*, from the endosperm of wheat. (Redrawn from Holman and Robbins, in *A Textbook of General Botany.*)

There is an important chemical substance in the plant which aids the changing of starch to sugar. This substance is **diastase,**

an **enzyme.** It is the same substance that occurs in saliva and which changes the starch of foods to sugar. The change is known as **digestion.** In digestion, a substance is changed into a form which allows it to readily diffuse from cell to cell. Digestion must not be confused with the process of assimilation. The latter is a change of non-living material to living.

The Nature of Enzymes.—We have just mentioned one important enzyme, **diastase.** It is a complex, organic compound, which has the one power of converting starch to sugar. Its exact chemical composition has not yet been determined. In

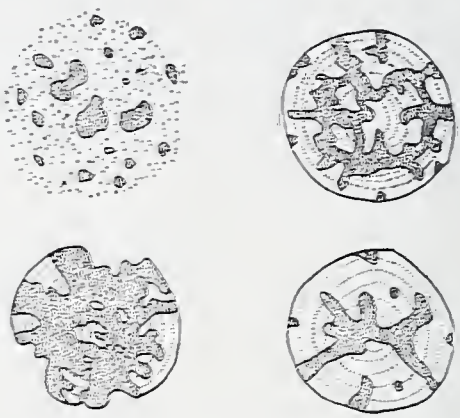

FIG. 105.—The four figures show successive stages in the digestion of starch grains by the enzyme, diastase. (Redrawn from Strasburger; from Holman and Robbins, in *A Textbook of General Botany.*)

the plant body there are many different enzymes, all of which are very complex chemically. They are a product of living cells. Each one has a specific work to do in the plant. For example, **diastase** dissolves starch, **lipase** dissolves fats, **proteinase** dissolves proteins, etc. Enzymes are non-living substances which may be extracted from the plant, and carry on their special activity apart altogether from the organism. For example, if diastase in water is placed on some starch in a dish, the starch grains are slowly dissolved and changed in to sugar (Fig. 105). Enzymes lose their power if subjected to high or low temperatures. Each enzyme has minimum, optimum and maximum temperatures

of activity. Another peculiarity of an enzyme is that a very small amount of it is capable of digesting a large amount of substance; and, still more strange is the fact that the enzyme is not appreciably used up in the process.

Digestion, Translocation and Storage of Starch in the Potato.—Let us illustrate these three processes as they occur in the potato plant. The cells of the potato plant which contain chlorophyll manufacture sugar from carbon dioxide and water. Some of this sugar, as such, is immediately conveyed from the leaf and goes to various parts of the plant where it is used in respiration and to nourish the tissues. Some of it reaches the developing tubers underground. Some of it may form the basis for fats and proteins. And, a large proportion of it is converted to starch and temporarily stored in leaf cells. At night, when the sugar-making process has stopped on account of the lack of light, the temporarily stored starch is digested, that is, converted to a soluble form, which in this case is sugar. The agency causing this change is the enzyme **diastase.** The sugar moves out of the leaf, through the leaf stalk into the stem, down through conducting tubes of the vascular bundles, and into the tubers. This sugar is converted back into starch and stored in this form in the tuber. The potato tuber is a starch-storing organ. When the tuber is planted and begins to sprout, it becomes sweet, indicating that starch is being converted to sugar. Furthermore, actual test shows sugar on the increase and in transport to the developing sprouts.

Dependent Plants.—We have learned that the foods of all plants are the same. The chief food substances capable of nourishing the plant are **carbohydrates, fats,** and **proteins.** We have seen how chlorophyll-bearing plants are capable of making these foods. Plants which do not possess chlorophyll have not this power and consequently must absorb these substances already formed.

There are two great groups of dependent plants: (1) **Those** deriving their nutriment from **living** organisms; they are known as **parasites,** and (2) those deriving their nutriment from **non-living** organic material; they are known as **saprophytes.** The

rusts and smuts of cereals are good examples of parasites. Many of the molds are saprophytes.

Parasitic plants are among the chief enemies of crop plants. The loss from corn smut alone in the United States in 1917 amounted to our total export of corn. The annual loss from fungous and bacterial diseases of plants amounts into the millions of dollars. Many saprophytic plants are responsible for the decay of fruits and vegetables in storage. In Chapter XXII, we shall have more to say about fungi.

The nutrient substratum of most **independent** (green) **plants** is the soil. The root hairs are the organs which absorb the raw

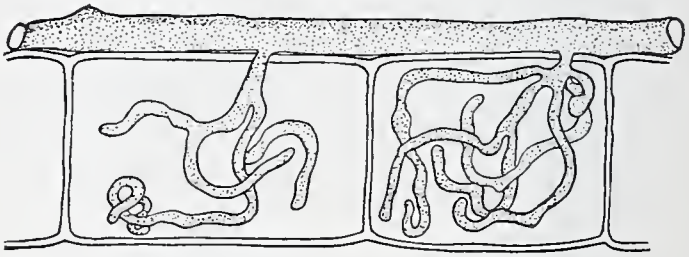

FIG. 106.—Haustoria of a downy-mildew. Two cells of the host are shown and part of a fungous thread showing the branching haustoria which have penetrated the wall and come in contact with the food of the cells. (Redrawn from De Bary.)

materials, with the exception of carbon dioxide and some oxygen, from the soil. The roots with their root hairs penetrate the soil, branching in all directions, and come into intimate contact with the soil particles and the water films surrounding them.

The nutrient substratum of **dependent** (**non-green**) **plants** is either the tissue of some living organism, or non-living organic material. Parasites and saprophytes do not develop roots with which to penetrate the substratum, but they have especially modified structures known as **haustoria** (Fig. 106). The haustoria of dodder are very typical. Dodder is a parasitic seed plant producing an abundance of seed resembling somewhat that of alfalfa and clover. The seeds germinate in the ground, and send out a slender yellowish or reddish thread-like stem. This

young growth is dependent upon the small amount of food stored in the seed. The stem in its growth sways back and forth in the air, and if by chance it comes into contact with a suitable plant upon which to live, it winds about that plant. Very soon at the points of contact between the dodder plant and the host upon which it is twining, small knob-like projections (**haustoria**) are sent out which penetrate the tissue of the host. These haustoria not only anchor dodder to the host, but absorb nutriment from the host. It is thus a parasite. The absence of chlorophyll in dodder indicates that it is incapable of making its own food. The food materials such as sugar, and soluble proteins which it absorbs from the host, were manufactured by the host.

The parasitic fungi also develop haustoria. In function they are very similar to the roots of independent plants in that they establish a nutrient relationship for the plant upon which they are produced.

The "Feeding" of Plants.—It is almost literally true that plants may be fed just as animals. The quantity and quality of the "food" available to a plant have an effect upon it similar to that upon an animal. An underfed plant is small and stunted in its growth; its "color" is not good; it is subject to attack by disease-causing organism. If the ration is not balanced, the effects upon the plant are evident. A lack of any one of the ten essential elements is at once evident. Moreover, an oversupply of some one substance may result in ill health or abnormality of growth. A well-fed plant—one which obtains an abundance of the right kind of "plant food," and at the proper time, becomes large, healthy and vigorous; its color is good; and its resistance to disease may be comparatively high.

The nutrient relations of plants are as different as are their bodily form and structure. There are plants such as blueberries which are intolerant of calcareous soils. We speak of plants which are "heavy feeders" and make great demands upon the soil. Tobacco is such a plant. Other plants are "light feeders" and do not draw heavily upon the chemicals in the soil.

When plants are analyzed chemically we see readily that they have taken varying quantities of the different mineral nutrients

from the soil, even when growing on the same soil. They make different demands upon the mineral elements in the soil. It must not be thought, however, that wheat, for example, growing in different kinds of soils and under varied climatic conditions, would take the same amounts or relative proportions of the different elements. We must consider averages, based upon the chemical analyses of crop plants made in many laboratories. For example, a wheat crop yielding 30 bushels of grain and 1.6 tons of straw, contains on the average 51.6 pounds of nitrogen, 8.6 pounds of phosphorus, 27.5 pounds of potassium and 5 pounds of calcium. A 200-bushel yield of Irish potatoes removes, on the average, from the soil 42 pounds of nitrogen, 6.3 pounds of phosphorus, 53 pounds of potassium and 55 pounds of calcium. A 15-ton crop of sugar beets takes from the soil 78 pounds of nitrogen, 10.5 pounds of phosphorus, 79.5 pounds of potassium, and 8 pounds of calcium. Thus we see that crops vary in their demands upon the different principal elements in the soil. Note in the figures above, for example, that a crop of wheat requires very much less potassium than a crop of potatoes, or of sugar beets, although it does require more nitrogen than potatoes.

An harvest of fruit from an orchard removes a certain amount of mineral elements, to which must be added that used in the making of leaves, stems and roots. For example, the fruit only of a 100-barrel apple crop will remove from the soil on the average about 13.8 pounds of nitrogen, 2 pounds of phosphorus, 14.5 pounds of potassium and 1 pound of calcium.

In the growth of plants for special purposes, man has attempted to find the nutrient conditions which will give him maximum production. He has learned that an abundance of water and of nitrates in proportion to potash makes for succulency in the plant, vegetative growth and scant fruit production. On the other hand, if the supply of nitrogen is withheld to a degree and potash in the soil is relatively more available, fruit production is stimulated. It is well known that tomatoes on a soil excessively rich in nitrogen "go to vine" and produce little fruit. In certain wheat-growing sections it has been shown that an excess of available nitrogen over potash in the soil gives a flinty, hard grain; and

that a starchy, mealy and soft grain results if there is a lack of nitrogen, and a relatively good supply of potash. Too much nitrogen, on the other hand, produces a tall plant, with a weak stem, which lodges easily.

Fertile and Infertile Soils.—In common understanding a "fertile soil" is one which will produce. A soil to be productive or fertile must have, of course, (1) the proper amount of water, (2) plenty of oxygen, (3) a supply of available mineral elements, (4) an absence of such harmful agents as fungous diseases, weeds, insect pests, alkalies, acids, and toxins, (5) the presence of certain beneficial bacteria and other fungi, and (6) a physical condition which is favorable to seed germination and root development.

In a more restricted sense, "fertility" or "infertility" has reference to the mineral nutrients, the so-called "plant foods" of the soil.

Man's control of the nutrient relation is largely concerned with making up a deficiency of some mineral nutrient brought about by the growth of plants. When a soil becomes "infertile," that is, incapable of producing a normal yield, the infertility is usually due to a lack of either **nitrogen, potassium** or **phosphorus.** These are the elements most commonly deficient in soils. The other essential elements are seldom lacking. Thus it is that artificial fertilizers contain one or more of these elements. Barnyard manure contains all of the elements which are necessary to increase a soil's productive power. Of course, it is true that manures of different farm animals differ in their chemical composition.

However, there is reason to believe that an infertile soil is not always due to a lack of essential mineral nutrients, although this is probably the most important cause. It appears that some soils with an abundance of mineral nutrients are nonproductive because of toxic substances in them. There is evidence that if a given crop is grown year after year on the same piece of soil, there accumulates in that soil toxic substances, which are deleterious to the growth of that plant. In this case, it would seem that one of the advantages of rotation is the counteraction of these toxic substances by the new crop. Further, it is

believed that the value of adding manure in a case of this kind is in counteracting the toxic substances in the soil rather than in adding mineral nutrients which are deficient.

In some instances, an unproductive soil may be due to organisms in the soil which attack the roots of the plant and cause disease. If one kind of crop is grown year after year on the same land, the soil fungi which prey upon that plant accumulate and the soil becomes non-productive, even though mineral nutrients are abundant.

Bacteria in Relation to Soil Fertility.—Contrary to popular opinion, not all bacteria are harmful. In fact many of them are absolutely essential in maintaining the life of the earth. Chief of these indispensable bacteria are those which bring about decay, breaking down complex organic substances such as proteins, fats, and carbohydrates into simpler substances that can be used again as raw materials in the manufacture of foods by green plants. Their presence and activity in the soil are necessary to maintain soil fertility.

Ammonifying and Nitrifying Bacteria.—Nitrogen is an indispensable element in plant growth. It is a constituent of the living material (protoplasm) itself. It is one of the principal components of both plant and animal proteins, and of many other chemical compounds in living bodies. It is well known that soil infertility is often due to a scarcity of available nitrogen, and that one of the principal ingredients of fertilizers is nitrogen in some form.

Nitrogen occurs in the atmosphere as a gas. About 80 per cent of the air is nitrogen. However, green plants are not able to absorb the atmospheric nitrogen and use it in the building of foods. Whereas nitrogen gas, along with carbon dioxide and oxygen, passes through the pores (stomates) of the leaf, it is not utilized by the plant in the free, gaseous form.

Nitrogen occurs in combination with many other chemical elements. For example, ammonia is a combination of nitrogen and hydrogen, one part of nitrogen to three parts of hydrogen (NH_3). Ammonia is a **chemical compound** of nitrogen and hydrogen. The nitrogen in this compound is not **free,** but is

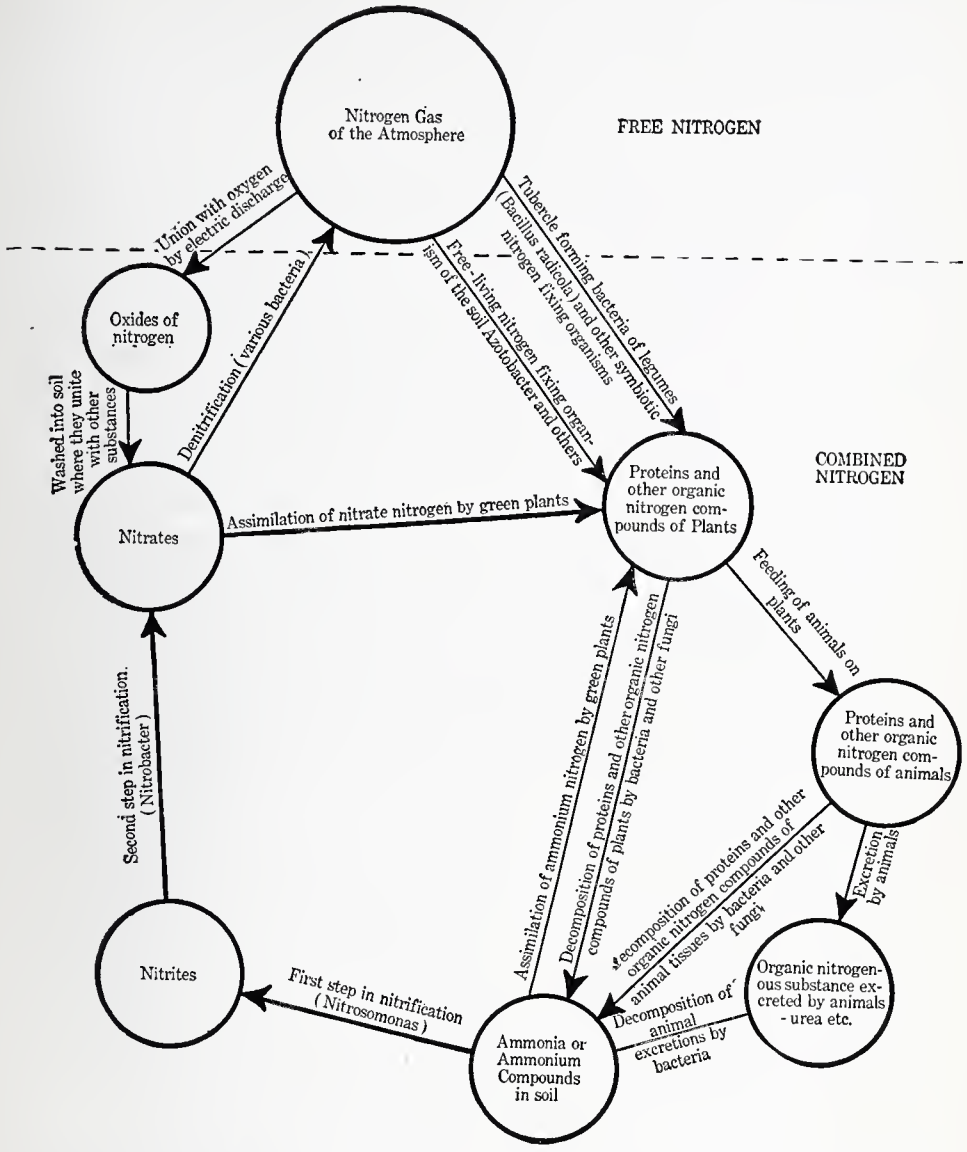
Nitrogen Gas of the Atmosphere
FREE NITROGEN
Union with oxygen by electric discharge
Tubercle forming bacteria of legumes (Bacillus radicola) and other symbiotic nitrogen fixing organisms
Free-living nitrogen fixing organism of the soil Azotobacter and others
Oxides of nitrogen
Denitrification (various bacteria)
Washed into soil where they unite with other substances
Nitrates
Assimilation of nitrate nitrogen by green plants
Proteins and other organic nitrogen compounds of Plants
COMBINED NITROGEN
Feeding of animals on plants
Proteins and other organic nitrogen compounds of animals
Excretion by animals
Organic nitrogenous substance excreted by animals - urea etc.
Decomposition of animal excretions by bacteria
Decomposition of proteins and other organic nitrogen compounds of animal tissues by bacteria and other fungi
Decomposition of proteins and other organic nitrogen compounds of plants by bacteria and other fungi
Assimilation of ammonium nitrogen by green plants
Ammonia or Ammonium Compounds in soil
First step in nitrification (Nitrosomonas)
Nitrites
Second step in nitrification. (Nitrobacter)

FIG. 107.—Diagram of nitrogen cycle. (From Holman and Robbins, in *A Textbook of General Botany.*)

bound to hydrogen. In other words, the nitrogen is **fixed.** Another very common chemical compound is sodium nitrate of Chili saltpeter. This compound contains sodium, nitrogen and oxygen in the proportion of 1 part sodium, 1 part of nitrogen and 3 parts of oxygen ($NaNO_3$).

There are a great many mineral salts containing nitrogen, but of these, sodium nitrate and its close relative potassium nitrate, are the most important as sources of nitrogen for green plants. The nitrogen in nitrates is spoken of as **nitrate nitrogen.**

As has been stated, nitrogen is one of the most important elements in plant and animal proteins. Manures are rich in nitrogen, for they contain plant and animal products. But the nitrogen in manures, or in any plant and animal refuse, is in a protein compound. It is **protein nitrogen.** It is significant that green plants can not use directly the nitrogen of proteins. It is necessary that the relatively complex protein compounds be broken down into simpler compounds of nitrogen, and that finally nitrates be formed. In other words, **protein nitrogen** must be changed to **nitrate nitrogen.** In all soils, under proper conditions, the nitrogen containing compounds of manure are being changed to nitrates. This change is dependent upon the activity of **three different kinds of bacteria.** If these soil bacteria are not present, or if conditions are unsuitable for their growth and multiplication, manure does not decompose, and nitrate nitrogen is not formed.

In the first place, the proteins of manure are decomposed through the activity of a group of bacteria known as **ammonifying bacteria,** and among the various decomposition products is ammonia, which of course contains nitrogen. The first step then is the change of protein nitrogen to ammonia nitrogen. Following this, another distinct group of bacteria changes ammonia nitrogen to nitrite nitrogen, and still another group of bacteria changes the nitrites to nitrates. The two groups of bacteria which change ammonia to nitrates are called **nitrifying bacteria.** In the three chemical changes brought about through the activity of soil bacteria, the unavailable protein nitrogen has been changed to the available nitrate nitrogen. In this latter form, the nitrogen

is readily absorbed by green plants, and utilized by them in the building of the proteins of their own bodies.

It is seen that the soil teems in bacteria which are extremely beneficial and essential. It is clear that conditions in the soil must be such as to promote their growth and development. These organisms require a good supply of oxygen, a certain amount of water and warmth, and the presence of calcium or magnesium compounds.

Nitrogen Fixation.—It was stated in a preceding paragraph that green plants cannot use free nitrogen gas of the air. The same is true of most plants, and of all animals. However, there are a very few bacteria and other fungi which are able to take free nitrogen and to build it into nitrogenous compounds of their bodies. Such organisms have the power of **nitrogen fixation.**

There are two principal groups of **nitrogen-fixing** organisms: (1) those which live on the roots of other plants, chiefly legumes, and (2) those which live without any association with the roots of higher plants.

Legume bacteria cause the development of tubercles or nodules on roots (Fig. 108). These tubercles or nodules vary considerably in size. Examination of a tubercle shows it to be composed of the swollen tissue of the host, in which are millions of the nitrogen-fixing bacteria.

How the Growing of Legumes Improves Soils.—It has been found that a clover plant, for example, secures about two-thirds of its nitrogen from the bacteria in the nodules, and one-third from the soil. Further, it is known that about two-thirds of the total nitrogen in the clover plant is in the tops (hay) and that the remainder is in the roots. Thus, it is seen that when a crop of hay is taken from the land, there is removed an amount of nitrogen about equal to that coming from the air, and fixed by nodule bacteria. The roots remain in the soil, in time decay, and the nitrogen they contain is returned to the soil. It will be clear from the figures given above, that if a clover crop is to enrich the soil in nitrogen, it must either be plowed under, or fed to animals and the manure, which of course, contains nitrogen,

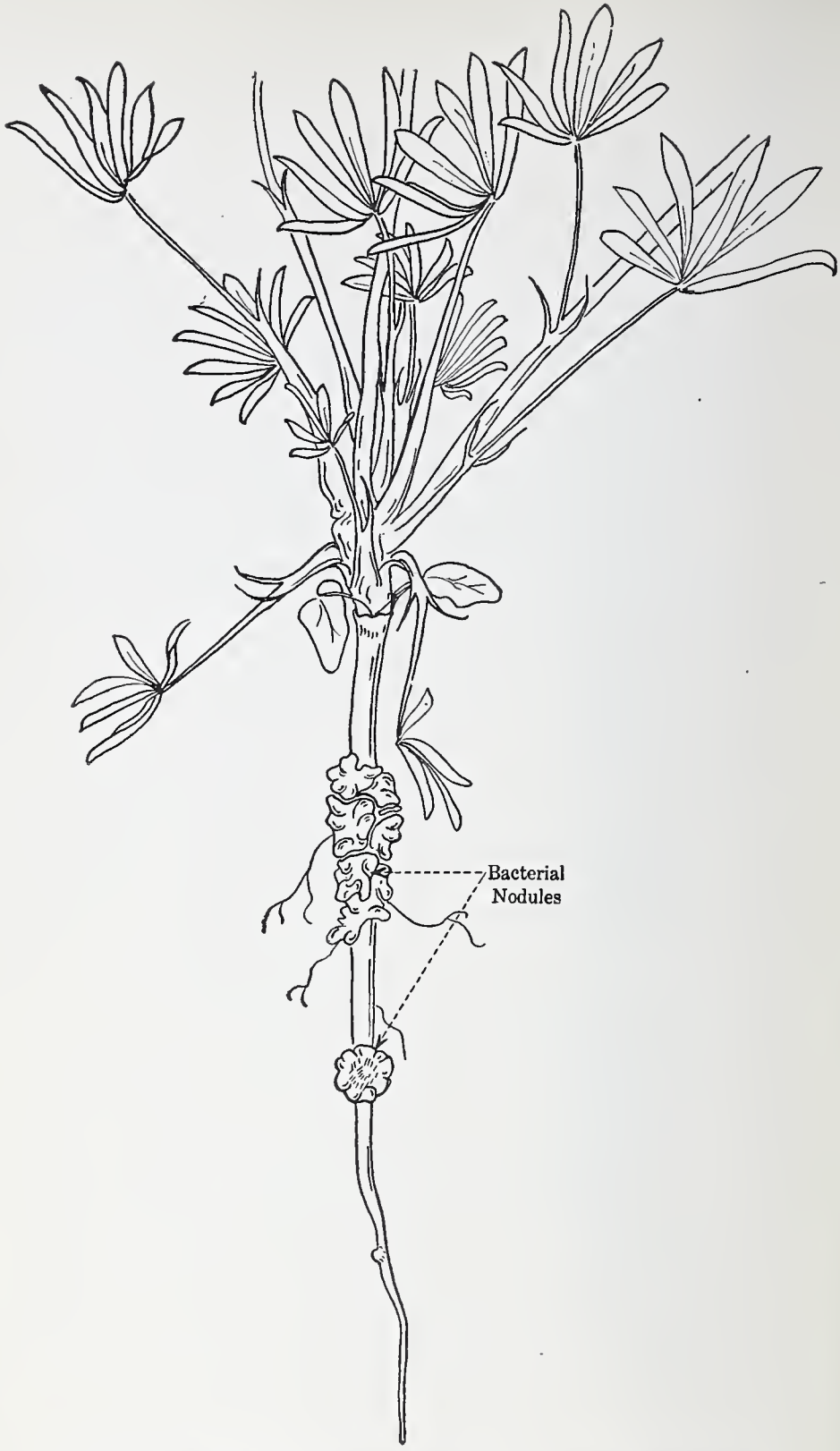

FIG. 108.—Bacterial nodules on the root of young lupine plant.

returned to the soil. If the hay is sold off the farm, the growth of the legume has not enriched the soil in nitrogen.

Denitrification.—In addition to the ammonifying, nitrifying and nitrogen-fixing bacteria of soils, there is still another group which plays a part in determining soil fertility. This is the denitrifying bacteria which change ammonia nitrogen to free atmospheric nitrogen. Such bacteria are undesirable from the soil fertility standpoint, for they take nitrogen from the soil. Denitrifying bacteria are most active in soils that are poorly drained and hence not well aërated, and in soils which contain large quantities of unfermented organic matters.

The Nitrogen Cycle in Nature.—As has been stated, nitrogen occurs in many different forms in nature: in the free gaseous form, as a part of inorganic compounds, such as ammonia, nitrites and nitrates, and as a part of organic matter, either in the non-living or living form. In the processes of nature, nitrogen is constantly being changed from one form to another. Through the activity of denitrifying bacteria, and in electric discharges, nitrogen compounds are being broken down and nitrogen set free. The free nitrogen of the air in turn is taken by certain bacteria and changed into proteins and other compounds of plants containing nitrogen. The nitrogenous compounds of plants are changed to ammonia; the ammonia to nitrites, and the nitrites to nitrates. The nitrates are then used to rebuild plant proteins. Or, plants are consumed by animals and the nitrogen of plants is used in the making of the nitrogenous compounds of animals. The organic nitrogenous substances excreted by animals and the dead bodies of animals undergo decomposition as a result of which nitrogenous compounds break down, liberating ammonia, which is in turn changed to nitrites, and nitrites in turn to nitrates. It is worthy of repetition to say that the processes of decomposition, of nitrification, of nitrogen fixation, and of denitrification, are brought about through the action of bacteria.

Storage of Foods in Plants.—We have learned that the foods of plants are carbohydrates, fats and proteins. During the life of the plant, there is usually an accumulation of one or more of these foods, for they are manufactured more rapidly than they

are used. They may be stored in different organs. In all crop plants, the seeds are storage organs. In annuals, only the seeds store food. It is readily understood why there would be no advantage in a food reserve in the roots, stems and leaves of annual plants. In biennials and perennials, on the other hand, large quantities of food may be stored in organs other than the seeds. For example, in the orchard trees, starches and sugars occur as a reserve in twigs, in the larger branches and the main trunk, and in the roots; these foods may be found in the bark, wood, and pith. The stems and roots of sugar maple and sugar cane contain much storage sugar. In many perennial weeds, like the Canada thistle, which live over the winter by means of underground stems, these organs contain a large amount of stored food. In the tuber of the Irish potato, in the fleshy tuberous root of the sweet potato, in the fleshy tap roots of such plants as turnip, carrot, and parsnip, there are stored large quantities of starch. The roots of the sugar beet contain as much as 15 to 20 per cent of sugar. Excellent examples of starchy seeds are corn, wheat, barley, rice, bean, pea, and alfalfa. The seeds of flax, cotton, and castor bean are known for the oil which they possess as a storage material. In some cases, seeds will contain considerable quantities of several different foods, starches, fats (oils) and proteins, for example; in the wheat kernel, starch and protein occur in the endosperm, whereas the germ is rich in oil. In corn the endosperm is richest in protein, containing 20 to 25 per cent; the hard, glassy part of the endosperm contains about 90 per cent starch and 10 per cent protein; the soft, mealy part of the endosperm is poor in total amount of protein; the germ or embryo has about 35 to 40 per cent of oil and 19 to 20 per cent protein.

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CHAPTER XIX

THE IMPROVEMENT OF PLANTS

THE improvement of plants is as old as agriculture itself. Men of all times have attempted to make their cultivated plants yield more bountifully. Increase in crop production has been secured for the most part by modifying the conditions under which the plants grow. In other words, our crops have been made to yield more and more by improving methods of cultivation, and farm machinery and by gaining a better understanding of the relation of plants to their environment. Hence it has become possible to get better yields than in former times, even with the same strains of plants. On the other hand, man attempts to increase production by the creation of new and better varieties.

Individuality in Plants.—No two plants are alike. When we look over a field of wheat of a given variety, or corn, or potatoes, all the individuals at first glance may seem to be much alike, yet on closer examination we can note slight differences in size, color, shape of leaf, etc. Plants have individuality just as animals. This is but another way of saying that the individuals of any strain show variation. The fact is, variation is a characteristic of all living organisms.

We recognize different kinds of variations in plants, as follows:

(a) *Modifications.*—These are minor individual variations which are largely due to differences in the soil, moisture, light, and other environmental conditions. If, for example, we planted the seed from a single self-fertilized wheat plant, the progeny would vary somewhat in height of plant, in length of heads, and in other characters, in spite of the fact that they have the same inheritance. The variations are induced by environmental influences. Variations of this kind are not inherited.

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(b) *Mutations.*—Practical growers have observed from time to time that among hundreds or thousands of plants of a given strain, there appear individuals with characters markedly different from those of the general population, which breed true to the characters in question. Variations of this kind are called mutations, and are popularly known as " sports." As stated, such variations are inherited, thus differing from continuous variations

FIG. 109.—Differences in clover plants from the same field. (From Jones, in *Genetics in Plant and Animal Improvement.*

discussed in the preceding paragraph. Examples of mutations are the red sunflower (Fig. 110), bush Lima bean, giant varieties of tobacco, and the Concord grape. No doubt within many of our fields of cultivated plants there appear from time to time these new forms, that is, mutations, and if we have an eye trained to pick them out we may often gain something to our advantage. The improvement of cultivated plants has frequently been brought about by the selection of mutations. Bud mutations or bud sports sometimes occur. Such bud variations originate in vege-

tative tissue. For example, there may occur on fruit trees a single branch which bears fruit differing in some particular from others on the tree. If the qualities are desirable, buds may be taken from the branch and used for multiplying the stock. Examples of bud mutations are certain varieties of the navel orange, and varieties of Boston fern.

FIG. 110.—Two heads of the red sunflower (at sides) and a head of the ordinary yellow sunflower (center). (Photograph furnished by T. D. A. Cockerell.)

(c) *Combinations.*—Various combinations of characters can be made by crossing. This type of variation will be discussed in a following paragraph.

Pure Lines.—The descendants of a single self-fertilized individual, all of which have the same genetic constitution, form a pure line. The common cereals, except rye and corn, and almost all legumes are usually self-fertilized, and consequently the populations are made up of one or more pure lines. In the case of plants such as corn and rye, which are naturally cross fertilized,

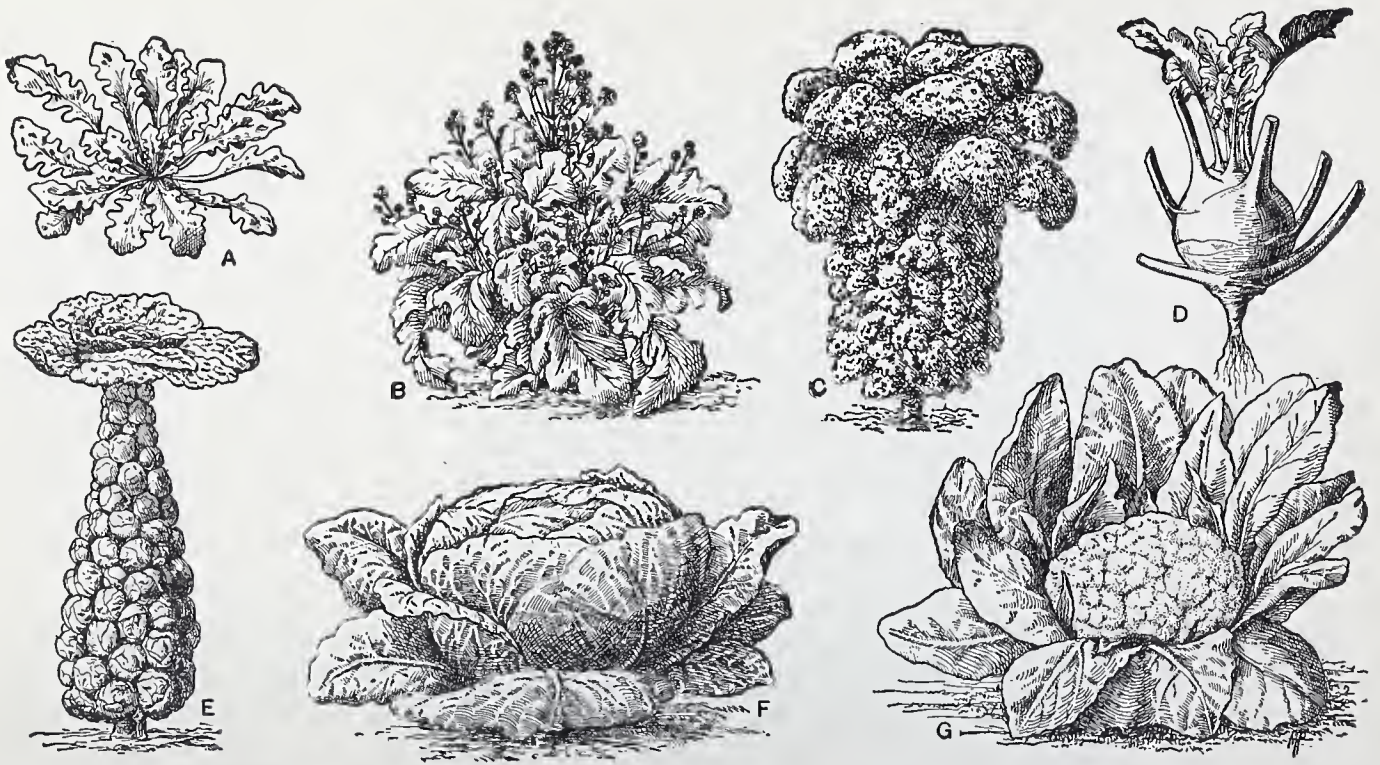

FIG. 111.—Horticultural varieties of the cabbage, believed to be mutations from the wild cliff cabbage. *A*, wild cliff cabbage; *B*, broccoli; *C*, kale; *D*, kohlrabi; *E*, brussels sprouts; *F*, common head cabbage; *G*, cauliflower. (From Gager, in *Fundamentals of Botany*.)

the populations are not made up of pure lines, but are highly mixed. However, long continued close inbreeding or self-fertilization in such cross-fertilized plants will produce a population the individuals which are very much alike as to their hereditary constitution.

As stated, it has been shown that most of our ordinary field varieties of naturally self-fertilized plants are composed of a number of pure lines. These various lines may differ from one

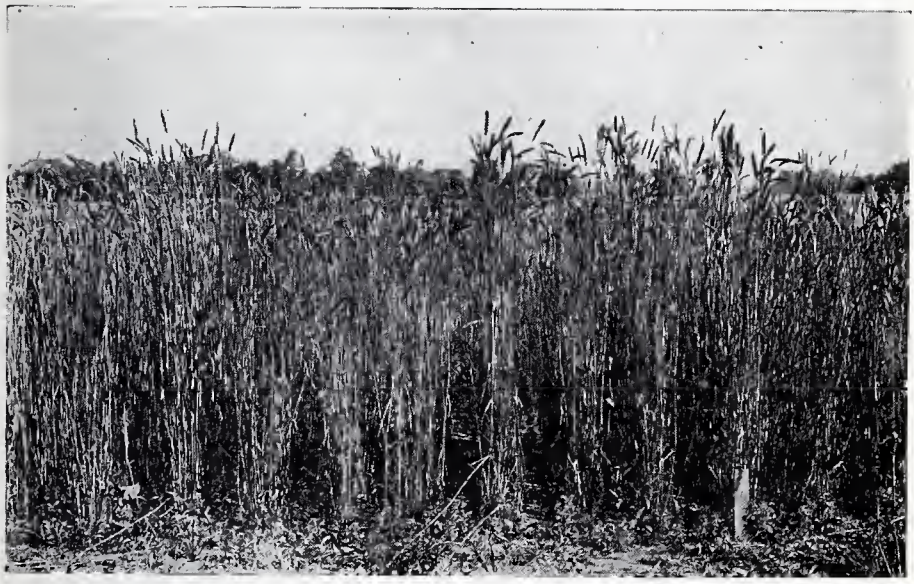

FIG. 112.—Rows of wheat, each of which was planted with the seed from a single head. (From Jones, in *Genetics in Plant and Animal Improvement;* after Love.)

another in a very marked degree. In order to isolate these pure lines from a mixed population, various methods are employed. In plants such as wheat, oats, barley, rice and most all legumes, which are normally self-fertilized, it is only necessary to select single individuals from the population, and keep the progeny of each separate. In the case of naturally cross-pollinated plants, like corn, approximately pure lines can be established by resorting to artificial self-pollination for a number of generations.

Let us follow through a case which will illustrate the principles

involved. Suppose that we go through a field of wheat of a given variety and pick out heads here and there from individual plants. Plants should not be selected from favored spots in the field, for such individuals may owe their desirable characters to the good environmental conditions rather than to their good inheritance. Let us plant separately in rows the seed from each of the different heads. Care should be taken that the different rows have similar conditions for growth and receive the same care. The next year we will have a number of rows of plants from as many mothers. We are now in a position to compare the progeny of each mother. Let us measure separately the length, say, of all the heads of plants coming from each of the mothers. We will find that the heads from the mother No. 1 vary, in length, for example, but the variation is within certain limits. All the heads from the mother No. 2 will vary within certain limits, and these limits may or may not be different from those of No. 1. The same for mother heads Nos. 3, 4, 5, etc. This is the so-called "head-to-row" method, used by plant improvers. We might have chosen any other character besides size and compared the rows. If one or more rows have promising or desirable characters, seed is threshed from them separately, and tested out the following season, again in separate rows or plots.

The number of pure lines that can be derived from a mixed population will depend upon the "impurity" of the variety from which selections are made and upon the original chance selections. Any amount of selection within a pure line will not modify that line, that is, will not change the limits of variation. That is, selection within a pure line is without effect. For example, in the case cited above, should we select the longest head from any one pure line the progeny from this large head would vary within the same limits as the race from which it came. The same would be true of the progeny from the smallest head of the same pure race. A notable example of pure line selection is Kanred wheat, the millions of individuals now in existence having descended from one single seed.

Mass Selection vs. Individual Selection.—In mass selection the seed from a number of desirable individual plants is chosen,

but that from each individual is not kept separate and planted by itself. Thus, one may collect in the field the heads of wheat from a number of individuals which appear to possess desirable characters; the seeds from these are mixed, and used as the source of the following season's crop. In such a case we plant seed from a number of mothers which may vary widely as to their hereditary constitution. Knowing that our ordinary varieties of wheat are usually made up of a number of pure lines and that the varieties may be separated into these distinct lines, it is seen that by a system of mass selection, we may, in picking out a superior

FIG. 113.—Different types of timothy obtained from single plant selections. (From Jones, in *Genetics in Plant and Animal Improvement;* after Webber.)

head, choose one which is superior only because of environmental conditions, while in reality it belongs to an inferior strain. Of course, it is true that by continuing mass selection from year to year, that is, by selecting the best seed each year for use the following year, a slow improvement will be secured. This is accomplished by a gradual elimination of the offspring of inferior strains in the field.

In the early history of plant improvement, mass selections was the practice almost to the exclusion of other methods. Today, it has been largely replaced by the method of individual selection, except for the purpose of raising and keeping up the general average of the crop. In individual selection, " pedigree-

culture," the progeny of a single mother plant is kept separate. By having the progeny of such individuals in rows or plots growing side by side, one may compare yields and select a desirable progeny. In actual practice, the farmer need only to go through his field of wheat, oats, barley, beans, peas, or any self-fertilized crop, select and keep separate the seeds from individual desirable plants, plant them separately, and by comparing the qualities of the different pure strains select that one which most nearly comes up to his standard. With crops that are naturally cross-fertilized it is necessary to isolate individual plants or make provision for their artificial self-pollination. It is important to remember that outside appearances seldom truly indicate the hereditary qualities of the plant. The best way to test the stability of these qualities of a plant is to examine its offspring.

Selection of Clones.—A clone is a "group of individuals produced from a single original individual by some process of asexual reproduction, such as division, budding, slipping, grafting, etc." Improvement of plants by the selection of clones can be made in the event vegetative mutations occur. Bud mutations, such as have been observed in certain citrus plants, offer material for clonal selection. Also, commercial varieties of potatoes, are known to be mixtures of different clones, and the improvement of such varieties may be brought about by selecting those clones which are most desirable.

Germ-plasm.—There is a certain part of the living material which is transferred from one generation of plants to another—from parent plant to its off-spring. This is called the germ-plasm. To illustrate, in wheat, the nuclear mass of the egg in the ovule, and the nuclear mass of the sperm in the pollen grain, when united, constitute the material which connects one generation of wheat plants with the next. All the other millions of cells which compose the parent plants do not contribute directly to the offspring, although they do support the reproductive cells. The germ-plasm is capable of developing a new body, which in turn dies after a time, but the germ-plasm itself lives on. Germ-plasm is continuous; the bodies which "house" it have a short life.

"Unit Characters."—We recognize that plants have certain characters, such as color of petal, shape of leaf, hairiness of leaf, character of bark, etc., which as such are inherited from their parents and are transmitted to their offspring. These have been called **unit characters.** The plant is considered to be a combination of unit characters. Moreover, it is believed that each unit character is represented in the germ-plasm by one or more of what has been variously termed a "gene," a "factor," or "determiner." For example, we may say that the egg or sperm carries the "gene," "factor" or "determiner" for yellow petal, or hairy leaf, or smooth bark, etc. There is something, either substance or condition, in the germ-plasm which controls the manner in which the plant develops.

Artificial Hybridization.—Artificial hydridization is a difficult practice except in the hands of a careful manipulator. In the crossing of different strains, the principal object is to secure ultimately progeny that will have **new combinations of characters.** The characters in such individuals are the same characters that were in the parents erossed. All that has been obtained is a new combination.

The usual mistake in hybridization is in not carrying the work for a sufficiently long period of time. Frequently, when two individuals are crossed and the hybrid is undesirable, the work is dropped entirely; the hybrid on further breeding might break up into a number of desirable forms. It is always well to produce progeny of the second, third, and even fourth generations, or until forms are secured which possess the desired characters.

Mendel's Law.—Due to the discoveries of Gregor Mendel, an Austrian monk, hydridization has ceased to be merely guess work. We are now able to proceed with much better understanding of the results to be gained. Mendel's law may be illustrated by describing one of his experiments and considering just one pair of characters.

One of the outstanding features of Mendel's work was his recognition of **unit characters,** and **their independence.** For example, he crossed a **tall** pea plant with a **dwarf** pea plant. Of course, it is clear that both the tall and dwarf plants were in pos-

session of a great number of characters. But, Mendel, for the purposes of his experiment, followed through the behavior of only the characters, **tallness** and **dwarfness.** And, he discovered that tallness acts as a unit, or that dwarfness acts as a unit, independent of all other characters. A cross between a tall pea and a dwarf pea, was always tall, no matter what the other characters of the individuals were.

As stated, Mendel crossed a tall variety of garden pea with a dwarf variety. That is, he took pollen from a flower of a tall variety and placed it on the stigma of flowers of a dwarf variety. Care was taken that the anthers of the flowers pollinated were removed before they opened and shed pollen on their own stigmas, thus effecting self-fertilization. The pollen grains from the tall variety germinated and grew on the stigmas of the dwarf variety and the pollen tubes reached the ovules. The nuclei of these pollen tubes carried, among others, the determiners of the unit character, **tallness.** When the nuclei fused there was formed a body (fertilized egg or zygote) bearing both the characters for tallness and dwarfness. The egg developed into the embryo of the seed, and by and by, following germination, grew into the adult pea plant. Now, Mendel found that this, and **all** other plants resulting from the crossing of tall and dwarf peas were **tall** individuals. They were not, as some might suspect, intermediate in size between the tall and dwarf plants, nor were some of them dwarfs. All of them were tall. These individuals are said to be hybrids as far as the two characters, tallness and dwarfness, are concerned. It is obvious that the hybrids, although tall, carry **hidden** the dwarf character. **Tallness** is said to be a **dominant character,** meaning that it dominates the contrasting character, **dwarfness,** which is said to be a **recessive character.**

Mendel found that when these hybrids were bred among themselves, or were self-fertilized, the offspring appeared in the proportion of 75 per cent tall individuals, and 25 per cent dwarf individuals. On further breeding it was found that one-third of the 75 per cent were pure tall individuals, that is, they continued to give tall plants generation after generation, if self-fertilized; and that two-thirds of the 75 per cent were hybrid

tall individuals, that is, broke up on subsequent breeding into the proportion of one pure to two hybrid tall individuals.

The behavior of the character pairs in crossing may be shown

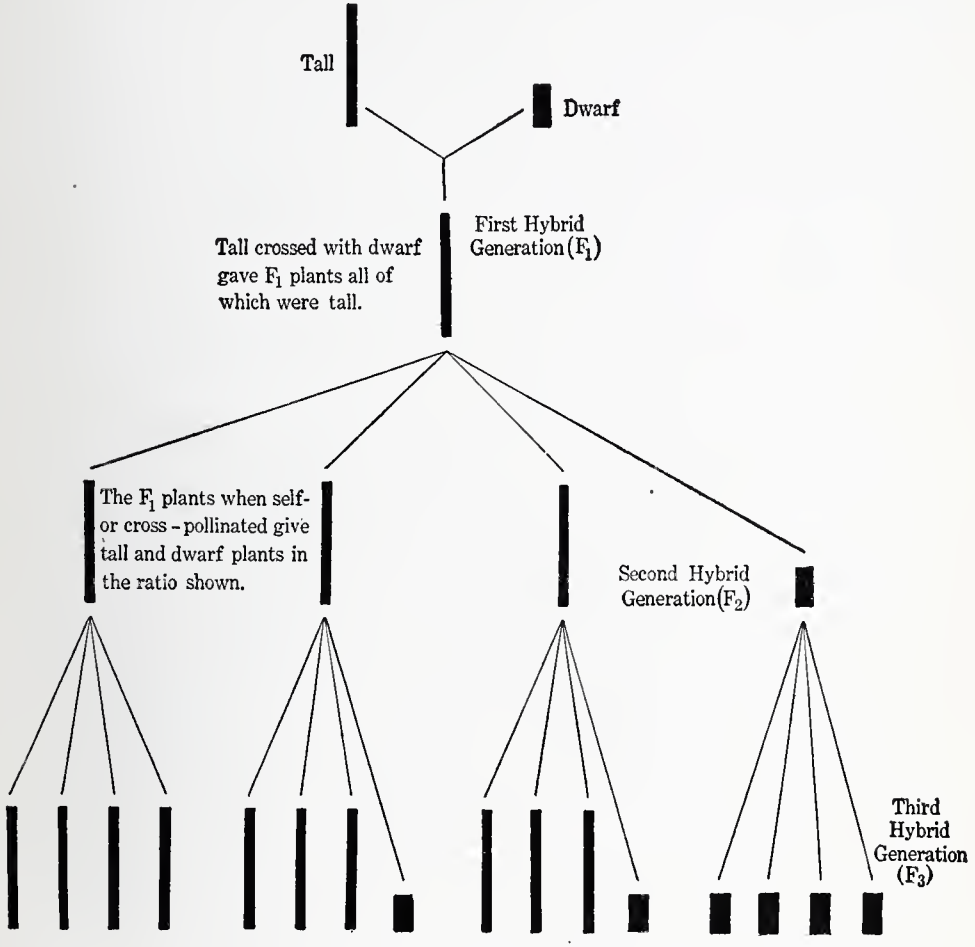
Tall
Dwarf
Tall crossed with dwarf gave F_1 plants all of which were tall.
First Hybrid Generation (F_1)
The F_1 plants when self- or cross-pollinated give tall and dwarf plants in the ratio shown.
Second Hybrid Generation (F_2)
Third Hybrid Generation (F_3)

FIG. 114.—Diagram illustrating inheritance is a cross between tall and dwar garden peas. (From Holman and Robbins, in *A Textbook of Genera Botany.*)

as follows: Let T stand for the character **tallness,** and D stand for the character **dwarfness.**

If a tall plant is self-fertilized, the nuclear material of the pollen grain carrying the determiner for tallness (T), will unite

with nuclear material in the embryo sac, which also carries the determiner for tallness (T); therefore, the fertilized egg nucleus, the embryo and the new plant will have a double dose of this character, which might be represented as TT. Likewise, if a dwarf pea is self-fertilized, the nuclear material of the pollen grain bearing the determiner for dwarfness (D), will unite with that in the embryo sac also carrying the determiner for dwarfness (D), and the resulting fertilized egg will have the composition DD. Now, it is clear that the composition of a hybrid should be represented as TD. In this case the fertilized (zygote) receives a single dose of each character determiner.

When a pea plant bearing the character for tallness (TT) comes into flower, the sperm nuclei in the pollen grain and the egg nuclei in the embryo sac all carry the determiner for tallness (T); and, the male and female nuclei in dwarf individuals (DD) all bear the determiner for dwarfness (D). That is, there is just one kind of pollen grain as far as these characters are concerned. But, when a hybrid pea plant, that is, one with the composition TD, comes into flower, two kinds of pollen grains are produced; although they have the same appearance under the microscope, one-half of the pollen grains carry the character T, and one-half the character D. Likewise, one-half of the egg nuclei of the hybrid bear the T character and one-half the D character. It should be emphasized that whereas the body cells of the pea plant may have the composition TD, for example, the male and female nuclei (gametes) carry one or the other, that is, either T or D. It will be seen then when hybrids (TD) are bred among themselves or are self-fertilized there are four possible combinations of characters, as follows:

(1) T (pollen) × T (egg) TT — pure tall.
(2) T (pollen) × D (egg) TD — hybrid tall.
(3) D (pollen) × T (egg) DT — hybrid tall.
(4) D (pollen) × D (egg) DD — pure dwarf.

The pure tall and hybrid tall individuals have the same stature, so that there are three tall offspring to one dwarf. But, although all the tall individuals have the **same appearance,** they do not

have the **same composition.** One-third of them are pure tall (TT), and two-thirds hybrid tall (TD or DT).

Let us take another example to illustrate one of the principal features of Mendelism. If a bearded wheat is crossed with a beardless wheat, all the hybrid offspring are beardless. But these hybrids, although beardless, carry hidden the bearded character. If these beardless hybrids are bred among themselves, the offspring will appear in the following proportions: 75 per cent beardless and 25 per cent bearded. On further breeding, it is found that the 25 per cent bearded always give bearded; that of the 75 per cent beardless, 25 per cent are pure beardless, while 50 per cent are hybrids, that is, are beardless, but like the original hybrids, conceal a bearded character. It is impossible to distinguish pure beardless forms from hybrid beardless forms except by further breeding.

In the two examples cited above we have used just one pair of characters: tallness and dwarfness in the case of peas, and beardedness and beardlessness in the case of wheat. If we consider more than one pair of characters, the case becomes more complicated. For example, in crossing a **smooth yellow** corn with a **wrinkled white** corn, the hybrid is **smooth** and **yellow.** Smoothness here is dominant over wrinkledness and yellow over white. Now, if these smooth yellow hybrids are bred among themselves, the progeny are in the following proportions: 9 smooth yellow, 3 wrinkled yellow, 3 smooth white, and 1 wrinkled white; thus making 16 possible combinations. Of these, 12 individuals are hybrids, 1 is pure smooth yellow, 1 pure wrinkled yellow, 1 pure smooth white, and 1 pure wrinkled white.

It must not be thought that in every case of crossing two characters one will be dominant over the other. For example, in crossing certain black-coated varieties with white-coated, the hybrids are gray. The essential feature of Mendelism is not dominance of characters; it is the segregation of characters in the second and third and following generations. The practical point here is this: Carry hybridization far enough to get at least second and third, or even fourth generation individuals, so that there will be a chance for a great number of new combinations

of characters. Save seed from the desirable combinations, compare, and propagate.

In the improvement of plants that can be propagated vegetatively, such as potatoes, many ornamental plants, fruit trees, and others, any individual which is selected, no matter to what generation it may belong, can be propagated and kept true by vegetative means. A hybrid propagated vegetatively will retain its hybrid characters, whereas if it is multiplied by means of seeds, it breaks up into a number of types.

Desirable hybrid plants that must be propagated by seeds, such as the cereals, must be "fixed," which means that they must be self-fertilized through a number of generations, each time selecting the desired individuals.

Range of Hybridization.—In general it may be stated that the more closely related two plants are, the more easily they may be crossed. However, there are exceptions to this, that is, races of the same species may not cross. Crosses between two strains of common bread wheat (*Triticum aestivum*) are more readily made than between bread wheat and Polish wheat (*Triticum polonicum*). And, although crosses between two genera, for example, wheat and barley, have been made, they are rare and apparently difficult to obtain. Experimentation must always be resorted to in determining the possibility of crossing.

Inbreeding and Hybrid Vigor.—It is a common observation that when certain plants are self-fertilized, that is, **inbred,** there results a loss of vigor. This is well illustrated in the case of corn, in which the progeny of self-fertilized plants is inferior in size, vigor and productiveness as compared with the offspring of cross-bred plants. Moreover, it has been observed that crossing certain inbred strains immediately restores vigor and productiveness (Fig. 115). Thus, the loss of vigor resulting from inbreeding is not permanent, but may be regained by crossing. In many other plants, hybrids frequently show greater vigor than either of the parents.

In the case of corn, a practical method has been worked out whereby high yields are obtained by using crossed seed. In this, the first procedure is to secure a number of inbred strains, and then determine by crossing which combinations give the best

yields. When a desired combination of two inbred strains is once found, crossed seed in quantity may be obtained by planting the two inbred strains in alternate rows. In one row the tassels (furnishing pollen) are left on, and in the other row the tassels are pulled out before the pollen is shed. The plants with the tassels left on will, of course, be self-pollinated, whereas those with the tassels

FIG. 115.—The result of crossing inbred strains. Weak golden-colored plants (left) when crossed with dwarfs (right) give all tall and vigorous progeny (center). (After Jones and Mangelsdorf, in Conn. Agr. Exp. Station Bulletin No. 273.)

removed will be cross-pollinated. The crossed seed (first generation hybrid) is used for the commercial planting. In this method of corn improvement, it is necessary to keep on hand a stock of seed of each of the inbred strains for production of hybrid seed. The second generation grown from the hybrids shows a decrease in yield often amounting to as much as 20 per cent. That is, it is necessary to use only the first generation crossed seed.

CHAPTER XX

THE CLASSIFICATION AND NAMING OF PLANTS

There exist to-day upon the earth over a quarter of a million different kinds of plants. Among the many kinds there are certain ones, such as the different maples, for example, which resemble each other more closely than they do any other plants. From the earliest times man has attempted to classify the large and varied assemblage of plants which he has found on the earth. He has sought to place those plants in the same group which are naturally related. He has not been content with artificial or arbitrary classifications. For example, in an artificial system he might choose to put all those plants with red flowers into one group, and those with blue flowers into another class, and so on, thus basing his classification on flower color. Or, he might put trees into one group, shrubs into another, and herbs into still another, thus basing the grouping on size and habit of growth. But it is obvious that yellow and blue violets are more closely related than are yellow violets and yellow buttercups, even though the flowers of the latter are of the same color. And it is clear that bamboo and corn are more closely related than are bamboo and oaks, although the latter two are both tree-like.

In the classification of plants, the reproductive structures, such as the flowers, are of great importance; apparently they are less influenced by environmental conditions than are vegetative structures, such as leaves, stems and roots. There may be little resemblance between the vegetative portions of two species, whereas their flowers may be very similar. For example, locust and alfalfa plants differ greatly in their size and form, yet the flowers of the two are constructed on the same general plan; and because of the similarity of their floral structures, they are placed in the same plant family.

The Four Principal Groups of Plants.—According to a widely used classification, the plant kingdom is divided into four principal groups, each, of course, containing thousands of different kinds of plants. These four divisions are as follows:

1. Thallus plants (*Thallophyta*).
2. Moss plants (*Bryophyta*).
3. Fern plants (*Pteridophyta*).
4. Seed plants (*Spermatophyta*).

The Thallus Plants.—The " thallus plants " include the simplest organisms. This group is divided into two large subdivisions, the **Algae** and **Fungi.** The Algae include the green scums so frequently observed upon the surface of pools, stagnant ponds, reservoirs, ditches and streams. They are also commonly found in tanks and water troughs, and in such places may render the water objectionable to stock, especially when decay sets in. The brown and red " sea weeds " are also Algae. The Fungi are a large group of plants, probably the best known being the bacteria, the molds of bread, fruit, and cheese, the rusts and smuts of the cereals, the toadstools and mushrooms, the mildews, and the fungi causing such well-known diseases as blight of potato, alfalfa leaf spot, apple scab, wilt of cucurbit, etc.

The Moss Plants.—This group includes the true mosses and the liverworts. They reproduce vegetatively, and by means of spores.

The Fern Plants.—The " fern plants " are represented by the true ferns, and closely allied plants such as the horsetails or scouring rushes, and club mosses. Like the preceding groups, fern plants do not produce seed but reproduce in a much simpler fashion, by spores.

The Seed Plants.—The most advanced and most complex group is the " seed plants." It includes the Gymnosperms (pines, spruces, firs, hemlocks, cedars, junipers and other cone-bearing plants) and the Angiosperms (higher seed plants or flowering plants). All the common crop plants of field, orchard, and garden belong to the Angiosperms. In the Gymnosperms the seeds are exposed, while in Angiosperms they are enclosed in a case, the ovary wall. Angiospermous plants fall into two groups (sub-

classes): (1) **Monocotyledons,** in which the seeds have one cotyledon, the flower parts are in threes, the leaves are parallel veined, and the vascular bundles are scattered throughout the pith (examples: cereals, onions, asparagus, lilies); (2) **Dicotyledons,** in which the seeds have two cotyledons, the flower parts are in fours or fives, the leaves are netted-veined, and the vascular bundles are in the form of a cylinder about the pith (examples: buckwheat, beet, apple, cherry, mustard, cotton, melon, potato). Each of these subclasses is further subdivided into **orders,** the orders into **families,** the families into **genera** (singular, genus) and the genera into **species** (singular, species). A complete classification of some plant, e.g., common alfalfa, will illustrate the system of plant classification.

Division—*Spermatophyta.*
Class—*Angiospermae.*
Subclass—*Dicotyledonae.*
Order—*Rosales.*
Family—*Leguminosae.*
Genus—*Medicago.*
Species—*Medicago sativa.*

Scientific Name.[1]—In seed and nursery catalogs the scientific, as well as the common, names of plants are referred to. Also, in many books and bulletins dealing with crop plants, reference is made to the scientific names of plants. Hence it is well that we know the meaning of scientific names. The system of naming plants and animals in use by all biologists to-day is the so-called **binomial system.** The scientific name of each plant (and animal) is composed of two words. For example, the scientific name of common alfalfa is *Medicago sativa L.* The first word, *Medicago,* is the name of the genus, or generic name; the second word, *sativa,* is the name of the species, or specific name. The letter "L" following the scientific name of the common alfalfa is the abbreviation for Linnaeus. Placed in this position after the name

[1] This account, and that in the two following pages, follows very closely that in *Robbins' Botany of Crop Plants,* published by P. Blakiston's Son & Co., Philadelphia.

of the plant, it signifies that the species was first named and described by Linnaeus, who was an early Swedish botanist.

Botanical varieties or subspecies are often printed as trinomials; for example, the dent subspecies of *Zea mays* (corn) is written *Zea mays indentata*. Agricultural "varieties" are designated by common names, for example, among the dent corns, there are such varietal names as Reid's Yellow Dent, Minnesota No. 13, etc.

The specific name of a plant has no definite meaning when used alone; it must always be used in connection with the generic name. For example, the specific name *vulgaris*, is used in combination with the generic name *Phaseolus* (*Phaseolus vulgaris*, bean), with the generic name *Beta* (*Beta vulgaris*, common beet), and with a number of other names of genera. The generic name, on the other hand, may be used alone. For example, the wheats belong to the genus *Triticum*, and this name applies only to the different kinds of wheats.

Descriptive Nature of Specific Names.—Specific names are commonly descriptive. They may be descriptive of (1) some plant character or habit, (2) habitat, or (3) distribution; and, in some instances (4) the species may bear the name of an individual. By far the largest proportion of specific names is descriptive of some striking habit or character of the plant. For example, the trailing or procumbent *Trifolium* (clover) is *Trifolium repens* (repens, creeping); the sweet clover with white flowers is *Melilotus alba* (alba, white); the narrow-leafed crab-apple is *Malus angustifolia* (angustus, narrow + folium, leaf).

In *Vitis riparia*, the streamside grape, **riparia** is descriptive of this species' habitat. The common black-cap raspberry is *Rubus occidentalis;* here the specific name means "western." Again, in *Vaccinium canadense*, the Canada blueberry, the specific name indicates geographical distribution. The systematist frequently uses the name of an individual for a specific name. This may be done as a token of friendship, or recognition of distinction, or to indicate the finder of the new form. For example, *Prunus besseyi*, is after the well-known botanist, Charles Bessey. The *i* ending is the Latin genitive, signifying "of Bessey."

Scientific Name versus Common Name.—There are distinct advantages connected with the knowledge and use of scientific names. Often the same species has many common names. Again, several distinct species often may go by the same common name. The use of one scientific name will do away with much misunderstanding as to what plant reference is made.

CHAPTER XXI

ALGAE

Algae are plants of simple structure which grow in the water or in very moist situations. We are familiar with those that form a greenish slime on the sides and bottom of watering troughs and drinking fountains; and those that appear as a green coating on the north sides of trees in moist forests; and those that form a green, frothy, repulsive-looking scum on the water of ditches, ponds, reservoirs, and stagnant pools. Algae are found in both fresh and salt water. Many of the larger kinds of the ocean are known as "seaweeds."

Four Different Groups of Algae.—As to color, there are four kinds of algae: blue-green, green, brown, and red.

The blue-green algae and green algae are chiefly of fresh waters, whereas the brown algae and the red algae are principally of salt waters.

The brown algae, or brown sea weeds, are common along the shores of all oceans. They are attached by specially modified structures, *holdfasts* (Fig. 116), to pilings, rocks, etc. The best known brown algae are the giant kelps, some of which may reach a length of from 800 to 900 feet, the **rockweeds,** which are found on the rocks between high-tide and low-tide marks, and *Sargassum*, which becomes detached from its growing places along shores, and is often carried far into the ocean. The "Sargasso Sea" in the North Atlantic Ocean is a floating mass of the brown alga, *Sargassum*, carried there by ocean currents from distant shores.

The red algae, or red sea weeds (Fig. 117), are very beautiful, delicate plants and are usually much smaller than the brown algae. The plants are often very highly branched, the divisions

being fine and thread-like. The red algae are found in deeper waters than the brown algae.

Are Algae Poisonous?—It is erroneously believed by some that the green scum itself is poisonous. The water may contain disease bacteria ("germs"), but the living algae are not responsible for its unsafe condition. Dead algae, however, are harmful

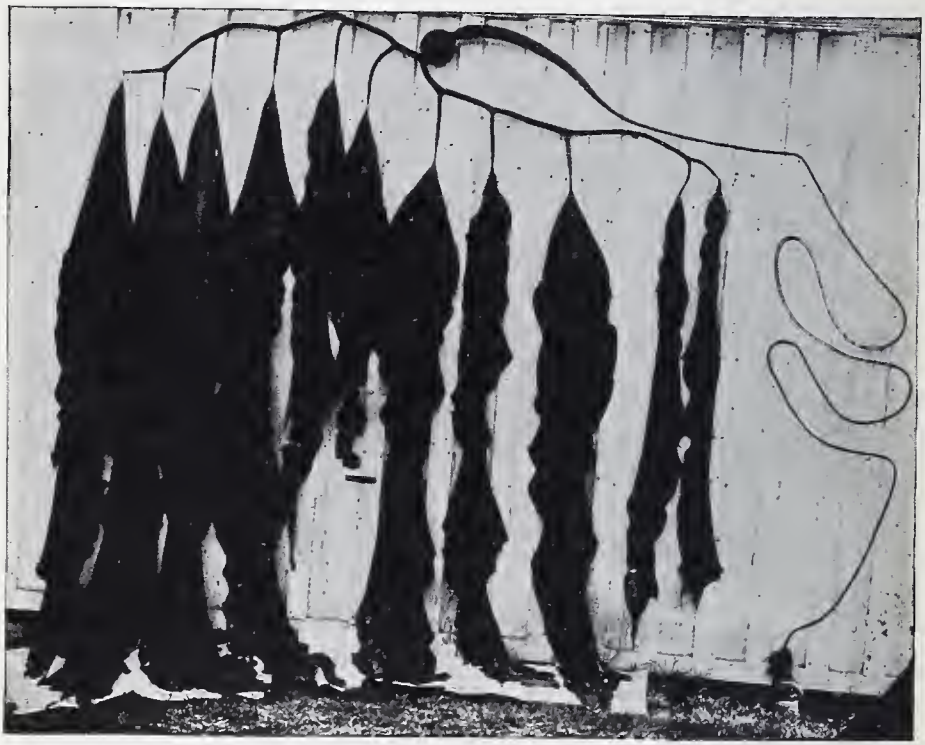

FIG. 116.—A large kelp (brown seaweed) from the California coast. (From Holman and Robbins, in *A Textbook of General Botany*. Photograph by W. W. Setchell.)

in that they furnish food for millions of bacteria, and the products of decomposition may be poisonous. In deserts, where small pools of water sometimes occur that contain poisonous minerals, travelers distinguish such pools from those having safe drinking water by the fact that no plant or animal life whatever exists in them. A spring with algae in it is a welcome sight, even if the water trickles over slime-covered rock.

The Structure of Algae.—All of the algae are relatively simple in their structure. They do not have roots, stems, and leaves in the ordinary sense. Moreover, they do not have flowers, fruit and seeds.

The simplest algae, such as *Gloeocapsa* (Fig. 118, A), and *Protococcus*, are one-celled plants. The whole plant consists of but one spherical cell. What simpler plant could there be? But these microscopic, one-celled plants carry on all the life processes, such as **absorption** of water and mineral nutrients which are taken in at all points on the plant body, **respiration, food manufacture, digestion, assimilation,** and **reproduction.**

Fig. 117.—A portion of a plant of *Polysiphonia*, a red seeweed. (From Holman and Robbins, in *A Textbook of General Botany.* Photograph by N. C. Gardner.)

Many of the algae are filamentous or thread-like forms. That is, their bodies consist of a single chain of cells. Common examples of filamentous algae are: *Nostoc* (Fig. 118, E) and *Oscillatoria* (Fig. 118, D) of the blue-green algae, and *Spirogyra* (Fig. 118, F) and *Ulothrix* of the green algae.

Nostoc plants are often aggregated to form bluish-green balls, which may be found on damp earth or in water. The threads or filaments (the plants) are imbedded in, and held together, by a gelatinous material secreted by the different cells that make up the colony. Chlorophyll is present and with it is a blue-green pigment which gives the blue-green color to the whole cell.

Spirogyra or common pond scum is one of the most widely distributed of the green algae. Each cell is a short cylinder, with well-defined walls of cellulose. Each cell has one or more conspicuous spiral chlorophyll bands (Fig. 118, F). The spiral band is a specialized mass of living material. In addition to it, there will be found near the center of the cell a **nucleus,** and from it strands of protoplasm radiating to and connecting with the protoplasm that lines the wall.

A number of algae such as *Cladophora* are branching, filamentous forms. Some, like *Ulva,* consist of a single plate of cells. The brown and red algae, however, possess the most complex structure of all the algae. Their bodies are large. In one of the rockweeds (*Ascophyllum*), for example, the plant possesses special holdfasts; it is highly branched, and the branches are of two different kinds; there are two quite distinct systems of tissues; and its reproductive organs are more complex than those in blue-green and green algae.

Thus we see that algae, as a group, vary considerably in structure. The blue-green algae include the simplest forms, many of them being simple one-celled plants. Some of the blue-green algae are filamentous. The green algae include one-celled, filamentous, and plate forms. The brown and red algae are often very large plants.

The Nutrition of Algae.—All the algae possess chlorophyll and hence are capable of manufacturing carbohydrates. Their mineral nutrients are absorbed from the water which usually surrounds them on all sides. Carbon dioxide and oxygen are dissolved in the water in which they live, and taken by the plant for use in carbohydrate manufacture and respiration respectively.

Reproduction of Algae.—We have said that algae have no seeds. They reproduce by much simpler means. It is well to bring to mind at this time that the **essential feature of reproduction, no matter what group of plants is being considered, is the separation from the parent plant of a cell or group of cells,** which is the beginning of a new plant. There are two general sorts of reproduction: (1) **Asexual** and (2) **sexual. Asexual reproduction** involves the division of cells only, and there is no union of cells.

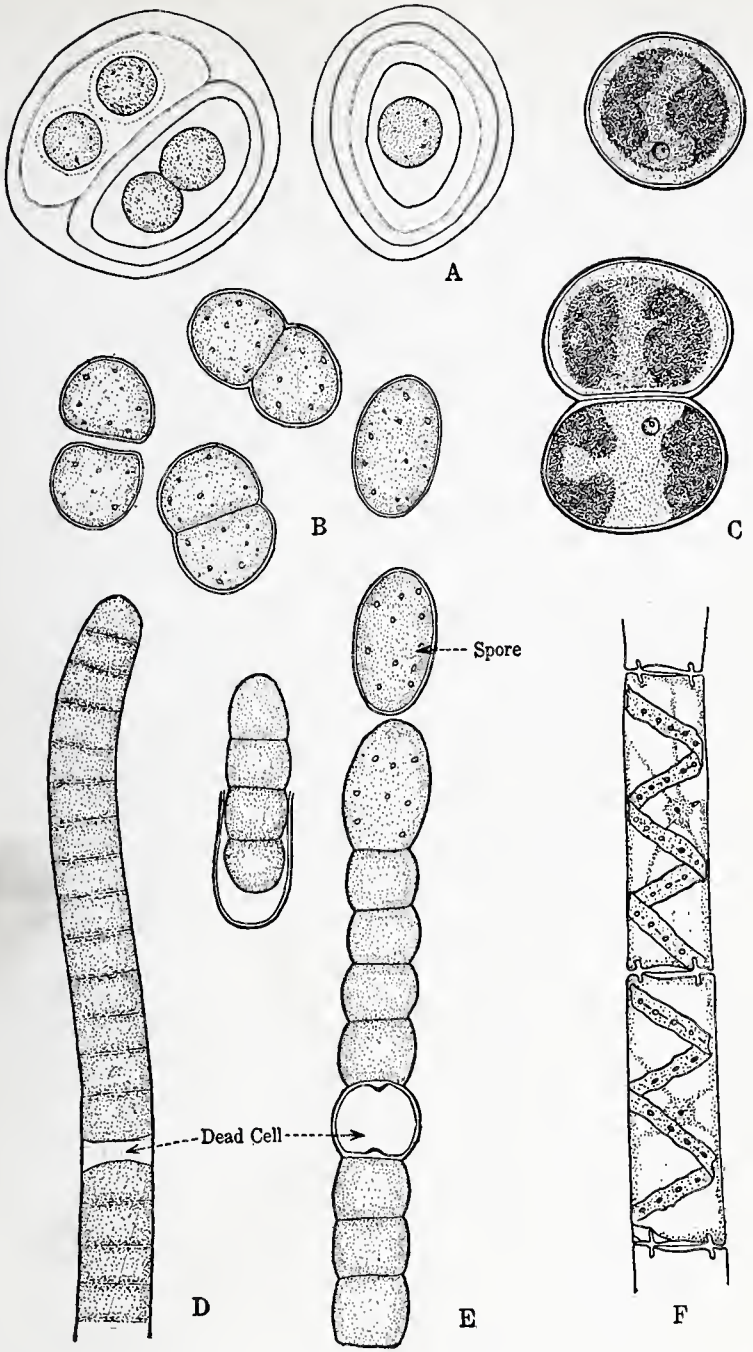

FIG. 118.—Different kinds of algae. *A*, *Gloeocapsa*, a blue-green alga in which the individuals are surrounded by a gelatinous coating; *B*, *Synechococcus*, a blue-green alga; *C*, *Protococcus*, a simple green alga; *D*, *Oscillatoria*, a thread-like blue-green alga; *E*, *Nostoc*, another thread-like blue-green alga; with germinating spore at left; *F*, *Spirogyra*, or common pond scum, a green alga. (From Holman and Robbins, in a *Textbook of General Botany*.)

In *Nostoc* (Fig. 118, E), for example, the chain of vegetative cells is interrupted at points by large, clear, dead cells. The chain may break apart at the dead cell, giving rise to a number of shorter chains, each of which lives independently as a new individual, and increases in length by the division of its cells. This method of reproduction is known as **vegetative multiplication** or **propagation.** It is best exemplified in a number of the higher plants, in which such many-celled portions as "slips," cuttings, tubers or bulbs are employed in reproducing the plant. Most of the algae possess the power of vegetative multiplication.

Another type of asexual reproduction is found in the algae. This is reproduction by **spores.** A spore is a single cell or small group of cells which separates from the parent plant and grows directly, without union with another cell, into a new plant. In *Ulothrix,* for example, the protoplasmic contents of a single cell may round up into a number of spores, which in time escape from the cell that produced them, and each is capable, under favorable conditions, of growing directly into a new *Ulothrix* plant. Each asexual spore of *Ulothrix* has four protoplasmic projections (cilia) which enable it to move about through the water. On account of its motility it is called a **zoospore.** With but few exceptions, the green, brown and red algae possess some type of reproduction by spores.

Algae also reproduce sexually. **The essence of sexual reproduction is the union of two masses of protoplasm.** In *Ulothrix,* for example, the protoplasm of a cell may divide into a number of bodies, similar in size, shape and behavior and much smaller than the asexual spores mentioned above. After escaping from the mother cell, the sexual bodies (gametes) unite in pairs. Ordinarily, a gamete is incapable of producing a new individual unless it fuses with another. The body resulting from this union of similar gametes is called a **zygospore,** and the process is known as **conjugation.** The zygospore develops a thick wall which enables it to better resist changes in moisture and temperature. It is a resting spore. After a period of rest, which may be the winter season, the zygospore produces a number of zoospores, each of which may form a new *Ulothrix* plant.

In the green, brown and red algae there is a type of sexual reproduction in which the gametes are very dissimilar in size, shape, and behavior; moreover, the organs which produce these two kinds of gametes are themselves quite different. This type is well illustrated in *Vaucheria*, a green algae quite common in slowly running streams and on moist soil, and commonly known as "water felt." The vegetative filament gives rise to two kinds of branches, which arise near each other. The shorter branch becomes swollen, spherical, develops a short beak, and forms a single large body. This is the **female gamete** and is called the **egg.** The longer reproductive branch is coiled. A cross-wall cuts off a terminal cell, in which are developed numerous small gametes. These are the **male gametes** or **sperms.** The sperms are motile. They escape through a pore in the tip of the cell which produced them, and are attracted toward the beak of the egg cell. Here, a single sperm unites with the egg or female gamete. This union of the sperm with the egg is a sexual act. The resulting body is the **oospore.** The process of union of dissimilar gametes is called **fertilization.** After a period of rest the oospore germinates and develops into a new plant.

The Destruction of Algae in Water-troughs, Ponds and Reservoirs.—Algae, of the green and blue-green kinds, may clog up water-troughs or they may become so abundant in ponds and reservoirs that their decomposed bodies may render the water obnoxious to the taste and smell, or become actually posionous. In such places they may be quite easily eradicated by the use of 1 part of copper sulphate (blue vitrol) in 1 million parts of water. Practically, this treatment is best effected by placing a few pounds of the crystals of copper sulphate in a sack, tying this behind a boat and rowing about the pond or reservoir. Fifteen pounds of copper sulphate to 1 million gallons of water is a practical proportion. In the case of a water-trough through which water is steadily running in and out, the suspension in the water of a small sack of blue vitrol for a short time now and then throughout the season will keep green scum from collecting. The small quantities of sulphate that go into solution are harmful to the algae, but do not injure livestock or human beings.

Economic Uses of Algae.—"Irish Moss" or carrageen is a red seaweed used for food purposes. It yields a mucilaginous carbohydrate which is employed in making jelly. Some of the brown algae yield gelatinous foods. The algae are also a commercial source of iodine. They also yield a slightly sweet crystalline substance, known as mannite. Agar, which is used as a medium in growing bacteria and also as a medicine, is made from certain red algae. Along the southern coast of California the utilization of seaweeds as fertilizers has developed into a large industry. The fossil shells of diatoms form the basis of certain scouring and cleansing preparations. Dynamite is nitroglycerin absorbed in diatomacous earth.

CHAPTER XXII

FUNGI AND PLANT DISEASES

The fungi are forms of plant life which do not have chlorophyll, and hence must secure their food ready made from living organisms or from substances which were once a part of the bodies of living organisms. The **foods** of fungi, as of all plants and animals, are chiefly carbohydrates, fats and proteins. As we have learned, **green plants** have the power of manufacturing these foods from carbon dioxide, water and various mineral salts, that is, from inorganic materials. But, the fungi, lacking chlorophyll, do not have this ability. They are **dependent** either directly or indirectly upon green plants.

Those fungi which gain their foods from living plants or animals are called **parasites;** those which take their foods from the dead remains or products of living plants or animals are called **saprophytes.** For example, the rusts and smuts which gain nourishment from live tissues are parasites; and the molds of bread and fruits, and the various fungi which grow on decayed logs are saprophytes. The term **host** refers to the plant or animal from which the parasite derives nourishment.

Different Kinds of Fungi.—There are many thousand different kinds of fungi, and they affect man's welfare in many ways. It is difficult to over-emphasize their importance. A number of bacteria and other fungi bring about decomposition of organic material, and are necessary to maintain soil fertility; thousands of them cause diseases of plants and animals, including men; they are essential in the making of cheese, of bread, in the retting of flax, and in many other commercial processes.

We shall discuss briefly here a few of the most important groups of fungi, namely, bacteria, molds, mildews, yeast smuts, rusts, mushrooms and toadstools.

The Bacteria.—*Occurrence.*—Bacteria teem in countless millions in the air, in the soil, and in the water; they are present upon the surface of the human body, and that of other animals, and in the intestinal tract; they abound in sewage, and in all decaying material; they occur in the surface of all objects about us.

Size.—Bacteria are the smallest known organisms. The average size is about $\frac{1}{25000}$ inch in diameter.

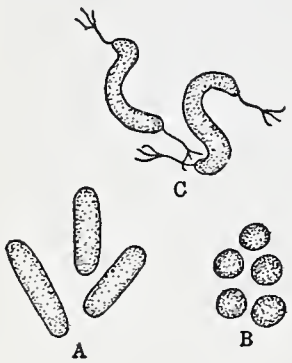

FIG. 119.—Three forms of bacteria. *A*, bacillus forms; *B*, coccus forms; *C*, spirillum forms.

Forms.—There are three principal types as to shape: the spherical (**coccus**), the rod (**bacillus**), and the spiral (**spirillum**) (Fig. 119).

Multiplication.—Bacteria multiply by simple division, and, under favorable conditions, at a very rapid rate. It has been computed that if a bacterium divides once an hour, in two days the offspring from a single individual would number 281,500,000,000. Of course, ordinarily this rate of reproduction would be interrupted by the exhaustion of the food supply or by the poisonous excertions from the bacteria themselves.

When one takes into account the rapid growth and multiplication of bacteria, it is little wonder that disease-causing species can be so destructive when they enter the body of plants and animals.

Some bacteria produce **spores.** These are thick-walled bodies which are resistant to low and high temperatures, and to other unfavorable conditions which the ordinary bacterial body could not withstand. For example, the spores of some bacteria will survive in boiling water, or at temperatures considerably below freezing; the spores of the bacterium causing a disease known as anthrax can remain alive as long as fifteen days in a 1 per cent solution of carbolic acid. The spores serve to tide the plant over a period during which conditions are unfavorable to growth; they are capable of germination when these become favorable.

The part that bacteria play in soil fertility was discussed in Chapter XVIII.

The Molds.—These usually form a cobwebby growth, and they occur on a great variety of organic materials, such as stale bread, fruit and vegetables, jellies, old leather, cheese and moist paper. Fruit and vegetables in the market, in storage, or during

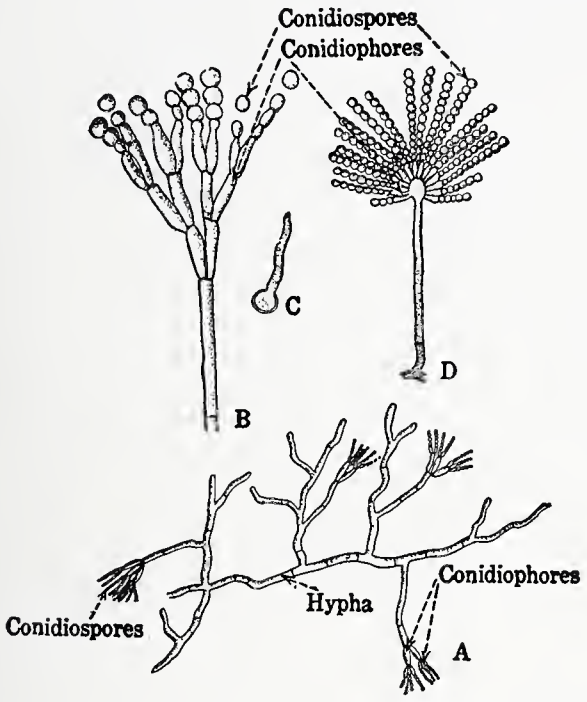

FIG. 120.—Blue and green molds. *A* and *B*, common blue mold; *C*, germinating spore of blue mold; *D*, green mold. An *hypha* is a fungous thread; *conidiophore* is a spore-bearing branch; *conidiospore* is a special type of spore. (From Holman and Robbins, in *A Textbook of General Botany.*)

shipment may be greatly damaged by these saprophytic fungi, especially if the air is warm and moist. To prevent their molding, such products are shipped and stored at low temperatures, often in refrigerator cars.

There are many different kinds of molds varying as to the color of the spores they produce: black, blue, brown, green and yellow (Fig. 120). All molds produce a tremendous number of

spores, which are very light in weight, and are carried far and wide by air currents. Mold spores occur in the air, and on the surface of bodies everywhere. They are very resistant to unfavorable conditions. They germinate quickly and form a moldy growth if it is warm and moist, and if a suitable food supply is at hand.

A bluish-green moldy growth often develops on hay, ensilage, fodder, and the kernels of corn, barley and other cereals, especially

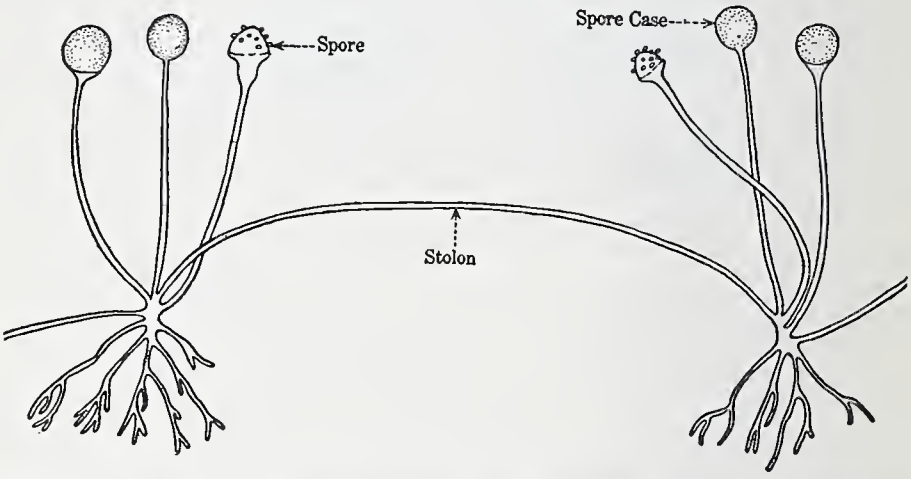

FIG. 121.—Bread mold, showing spore bearing cases, rhizoid-like branches and stolon. (From Holman and Robbins, in *A Textbook of General Botany.*)

when they are cured or stored under moist, warm or poorly-aired conditions.

Some of the molds are very poisonous to live stock, and others are not. The inability to tell which molds are poisonous should make farmers and stockmen cautious about feeding moldy foods of any kind.

Several species of molds are of importance in the manufacture of certain kinds of cheese, for example, Roquefort, Gorgonzola, Stilton and Camembert cheeses.

The Mildews.—There are two different groups of mildews, the **downy mildews,** and the **powdery mildews.** Both groups are parasitic. The mildews of the first group form a downy white

growth upon the surface of leaves, and sometimes of stems and fruits. The parasite is not confined to the surface, however, but its threads enter the tissues and absorb food from them (Fig. 106). The spores are borne in abundance on the surface of the host, and under suitable conditions will germinate immediately. Well known destructive downy mildews are those causing the late blight of potato, and the mildew of grape, onion, lettuce, lima beans, cucumber, pumpkin and watermelon.

The powdery mildews are parasites which live on the surface of the hosts; they do not penetrate deep into the host tissues, as is the case in the downy mildews, but send short absorbing organs into the epidermal cells only. The summer spores are formed in large numbers on the surface of the host. Later, there develop on the host small, black, spherical spore-bearing bodies, somewhat smaller than a pin head, from which extend a number of peculiar arms. The bodies are thick walled, and resistant to unfavorable climatic conditions. They rest throughout the winter, and in the spring break open and permit the spores within to escape. These are carried by the wind, germinate, and infect new plants.

Common powdery mildews are those of gooseberry, peach, rose, apple, cherry, pea, and lilac.

The Rusts.—The rust fungi constitute a very large group of plants, all of which are parasites, and many of which are of great economic importance on account of their destruction of crop plants. Among the most important rusts are those of the cereals, asparagus, apple, raspberry, and pine. The black stem rust of wheat, oats, barley and rye and other grasses has caused damage to the cereal crops amounting to millions of dollars, and at times has become epidemic. In the United States in 1916, the black stem rust caused a loss of wheat amounting to 200,000,000 bushels. The white pine blister rust has threatened the destruction of the white pine forests, the timber of which is valued at $411,000,000.

As stated, the rusts are parasites. The fungal threads penetrate the tissues of the host. Spores are produced in rusty patches on the surface of the host.

The life history of some rusts is very complex (Fig. 122). For

example, in the case of the black stem rust of small cereals, there are four different kinds of spores; moreover, a part of its life is spent on the cereal host and another part on the common barberry

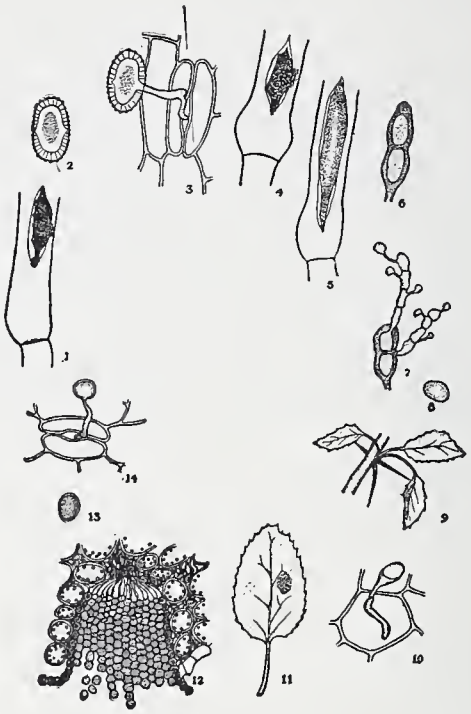

Fig. 122.—Life cycle of black stem rust. 1, red or summer rust stage on wheat; 2, a single red or summer rust spore; 3, germinating summer spore on surface of stem of another wheat plant, the germ tube entering a stomate; 4, within the tissues of the host fungous threads of rust are formed, and another crop of red or summer spores develops; 5, black or winter rust stage on wheat; 6, a single spore of black or winter rust; 7, these black spores remain alive on the ground or stubble and germinate in the spring, producing short tubes each usually giving rise to a spore of another type, known as sporidium; 8, single sporidium; 9, portion of common barberry plant upon which sporidia germinate; 10, sporidium germinating on surface of barberry leaf; 11, rusted patch or cluster cup on under surface of barberry leaf; 12, section of cluster cup showing spores; 13, single spore from cluster cup on barberry; 14, spore from barberry germinating on surface of wheat plant, and germ tube entering a stomate. (From Holman and Robbins, in *A Textbook of General Botany;* adapted from figure in Bulletin of the Minn. Agr. Exp. Sta.)

(*Berberis vulgaris*) (Fig. 122). Thus there are two different host species, and the rust can not carry through its complete life cycle, at least in the colder climates, unless both hosts are present. On the wheat, oats, rye or barley plant, are produced two kinds of spores, **red** ones in the early summer, and **black** ones in the fall. The red, or summer spores, may germinate immediately, the rapid progress of the disease during the growing season being due to their spread. The black, or winter spores, rest over the winter on stubble or grass. In the spring these black spores germinate, and produce a small microscopic growth which in turn produces tiny spores, which are capable of germinating only on the barberry plant. There is developed on the barberry plant a rust, which is evident by the yellowish cluster of spores on the under side of the leaves. These spores on the barberry spread rust from the barberry to grains. Knowing that the barberry bush harbors one stage in the life history of black stem rust of wheat, and realizing the enormous losses to the cereal crops from this disease, in 1918, there was started in the thirteen principal-wheat-growing states a vigorous barberry eradication campaign. This has progressed to the point where beneficial results are noticeable.

Other examples of rusts with two hosts are the white pine blister rust, which lives on the white pine and the leaves of currants and gooseberries; and the apple rust, which spends one part of its life on the apple and another on the cedar tree.

The Smuts.—All the smut fungi are parasites, occurring chiefly on members of the grass family. The annual losses of cereal crops due to the smuts, frequently amount to 150 millions of bushels. The smuts may be recognized by the black masses of spores. In cereal smuts these usually develop in the head and mature at about the same time the head matures (Fig. 123).

There are some differences in the life histories of the common cereal smuts, which must be taken into consideration in devising methods of control. In corn smut (Fig. 124), the black spores may germinate as soon as they are shed, or they may rest over the winter season. Each germinating spore develops a short microscopic thread which in turn produces several smaller spores. The latter are capable of rapid division, especially in barnyard

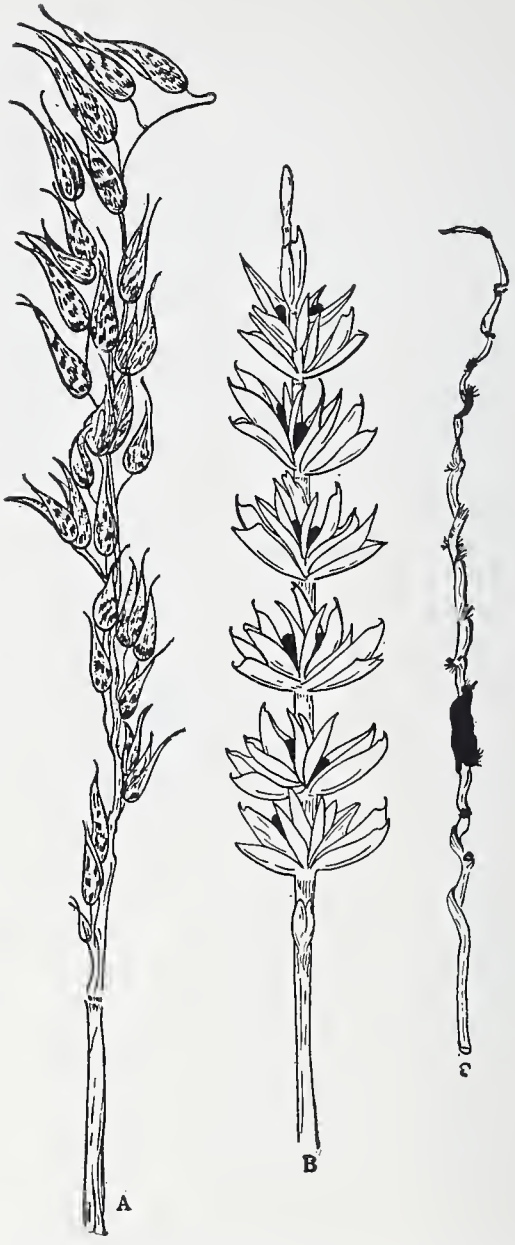

FIG. 123.—Heads of cereals affected by smut. *A*, smut of oats; *B*, bunt or stinking smut of wheat; *C*, loose smut of barley.

manures. They are blown by the wind. **Any part of the corn plant**—leaves, stems, "ear" or "tassel"—may be infected. The spores germinate on the host sending threads into its tissues, from which food is absorbed. If the corn plant is infected when

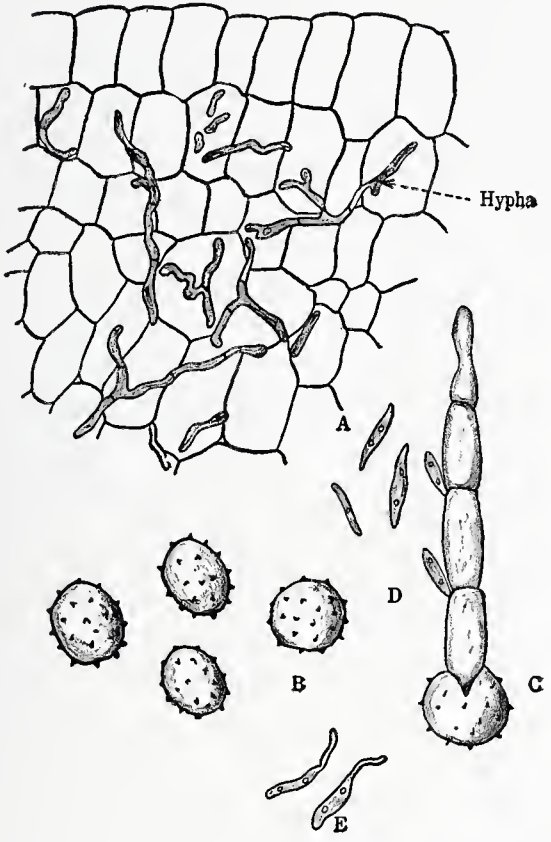

FIG. 124.—Corn smut. *A*, fungal threads in the tissue of the host; *B*, mature spore; *C*, germinating spore, showing the 4-celled tube which bears sporidia (*D*); *E*, budding sporidia. (From Holman and Robbins, in *A Textbook of General Botany*. Redrawn from Freeman and Stakman.)

young, the smut threads grow along with the corn plant, and there may be no evidence, other than reduced growth, that the plant is diseased. Later, however, the spore masses are formed.

In stinking smut or bunt of wheat (Fig. 123), smuts of oats, and certain other smuts, the plant is **infected only in the seedling**

stage. Infection comes from spores adhering to the grain, or in the soil. When the grain germinates, the spores also germinate and send threads into the young plant. The parasite keeps pace with the host in its growth, and becomes evident only when the host comes into flower. Then the fungus produces spore masses, which replace the grain. The smuts of this class are successfully controlled by treating the seed prior to planting with some chemical which will destroy all spores sticking to it, or will prevent the growth of spores already in the soil. Effective remedies are formalin, copper sulphate and copper carbonate.

In the loose smuts of wheat and barley (Fig. 123), the plant is **infected only in the flowering stage.** If the developing ovary of the flower is infected, the fungus forms a few delicate threads within it, but the grain's development is not retarded. In this case, a normal appearing grain may harbor the dormant smut within. When the grain germinates, the parasite begins to grow, and keeps pace with the developing host plant. But it is not until flowering time that the smut appears. Then the head becomes a black powdery mass. In order to control a smut of this class, the seed must be treated in such a way that the fungus within will be killed, but the young plant will be unharmed. A hot water treatment has proved successful.

Mushrooms and Toadstools.—These are fleshy fungi which are found growing in fields, pastures, and woodlands, and also upon decaying logs and tree trunks. There is a great variety of "mushrooms" and "toadstools." Probably the best known are those which bear gills and are known as the **gill fungi** or **"agarics"** (Fig. 125). Others are the pore fungi, the tooth fungi, the carrion fungi and the puff-balls.

Let us describe very briefly the common "meadow mushroom," the familiar edible one. The "mushroom" as we see it consists of a stalk and an umbrella-shaped cap. On the under side of the cap are thin gills. The spores are borne in enormous numbers on the surfaces of these gills (Fig. 126). Each spore is a microscopic spherical body, light in weight, and capable of being carried long distances by air currents. The cap with its stalk, constituting the "mushroom," forms in reality only a small part of the plant body.

The " mushroom " is a fruiting body and arises from a great mass of fungous threads which are distributed in the soil, and which gain their food from decayed organic matter.

The so-called mushroom " spawn " sold by seedsmen usually consists of dried manure containing the fungous threads, all being pressed together in brick form. When a mushroom bed is made, the " spawn " is broken up, mixed with earth, and used to start the beds. The " mushroom " originates from the fungous threads in the ground.

In the tooth fungi there are teeth or spines on the under side of the cap, and these bear the spores. In the pore fungi the

Fig. 125.—Common edible meadow mushroom. The cap and stem are whitish, the gills are pink at first, later brown, and on the stem there is a ring.

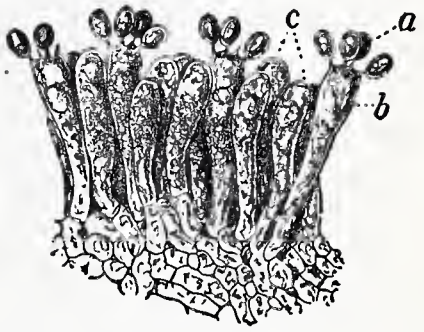

Fig. 126.—Small portion of a section through the spore-bearing layer of a mushroom. *a*, spores; *b*, spore bearer; *c*, sterile threads. (After Longyear.)

spores are borne in open tubes or pits on the under side of the cap. A number of pore fungi cause the rotting of wood. The puff-balls when mature rupture, setting free black clouds of spores.

A number of the fleshy fungi are poisonous. Although there is no botanical difference between " mushrooms " and " toad-stools," the former name is commonly applied to those believed to be edible, and the latter to those thought to be poisonous.

Nearly all the deadly poisonous fleshy fungi are species of the genus *Amanita*. This is a group of mushrooms with gills. Some of the species of *Amanita* have white caps, others have bright orange, red or yellow caps; but in all cases the gills are white.

This deadly poisonous group is distinguished by the following combination of characters (Fig. 128).

1. White gills.
2. A " ring " on the stem.
3. A cup at the base—the so-called " death cup." When a mushroom shows these three features, it should be avoided. One should not depend upon the various rules-of-thumb for detecting poisonous mushrooms.

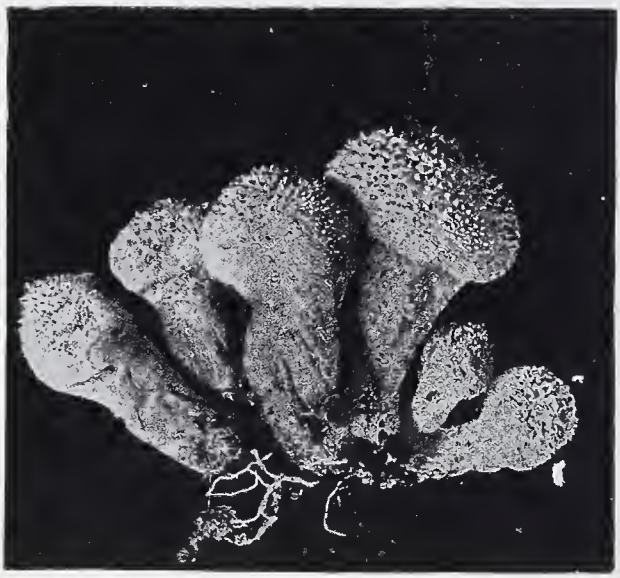

Fig. 127.—Puff-balls. (After Longyear.)

Plant Diseases.—One may express surprise that plants, as well as animals, become diseased, that they get " sick," and that they may need care and treatment to prevent them from succumbing to various maladies. But such is the case. The " plant doctor," or rather the plant pathologist, studies the characteristic symptoms of plant disease, he determines the causes, and searches for preventive measures and remedies. The science of plant pathology has made very rapid strides in recent years and the plant pathologist is a very indispensable person in our agricultural development. There are now scores of trained plant pathologists connected with

the United States Department of Agriculture, and with the various Agricultural Experiment Stations and Colleges.

It is estimated that the annual loss in the United States from potato blight amounts to $36,000,000, from wheat bunt, $11,000,000, and from oat smut, $6,500,000. The rust caused a loss of

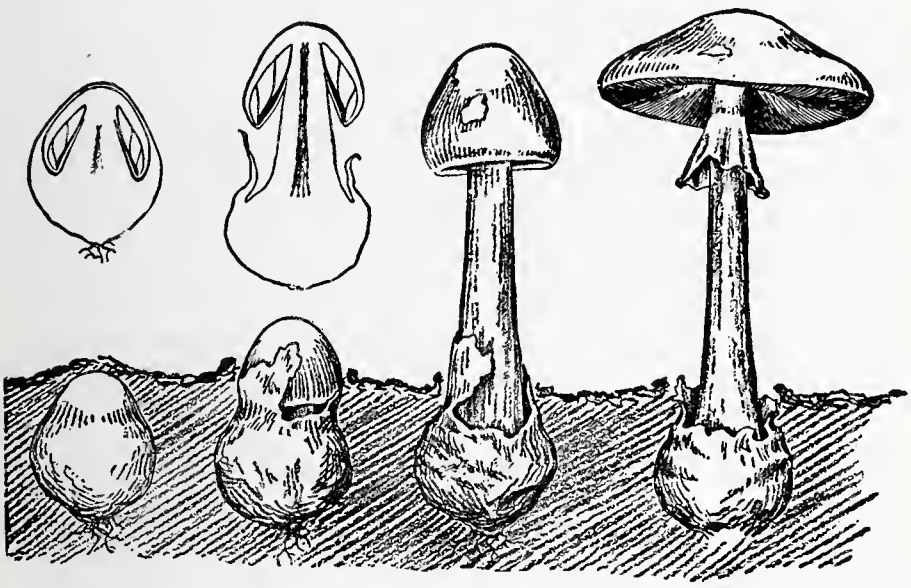

FIG. 128.—Stages in the development of a gill fungus. This is *Amanita*, a poisonous mushroom. (After Longyear.)

about 200,000,000 bushels of wheat alone in the United States in 1916.

The Causes of Plant Diseases.—The different plant diseases may be classified as follows, according to their causes:

1. Those caused by the activity of living organisms.
   - (*a*) Caused by animals, such as worms and insects.
   - (*b*) Caused by plants.
     1. Parasitic bacteria, and other fungi, and slime molds.
     2. Parasitic seed plants.

2. Those due to adverse non-living environmental factors such as the chemical and physical condition of the soil, light, heat,

precipitation, wind, lightning, smoke, soot, gases and smelter fumes, which may result in nutritive disturbances within the plant.

Diseases Due to Attacks of Bacteria.—Some of the chief bacterial diseases of cultivated plants are bacterial blight of alfalfa, blight of apple and pear, bacteriosis of bean, crown gall of a number of different plants, black rot of cabbage and wilt of cucurbits. Bacterial diseases are often very destructive and spread rapidly. The bacteria gain entrance to the plant through wounds or through the pores (stomates) in the leaves. In the tissues of the host the bacteria find a suitable food supply, and there grow and reproduce rapidly. Bacteria are dependent organisms and draw their food from the host, causing in it nutritional disturbances and structural modifications which have characteristic symptoms.

Diseases Caused by Parasitic Fungi.—The large majority of plant diseases caused by plants are due to the activity of parasitic fungi. Well-known diseases brought on by these organisms are the mildews, the spots, rots, scabs, wilts, smuts, rusts and cankers.

Diseases Caused by Parasitic Seed Plants.—There is one very harmful seed plant which lives a parasitic life on a number of different plants, but is most harmful to alfalfa and clovers. This plant is dodder or love-vine. Dodder plants have slender, thread-like stems of a yellowish or orange color which twine and coil about the alfalfa plants. The dodder seeds germinate in the soil about the same time as alfalfa seeds. Later, the plants lose all connection with the soil. As the alfalfa plants grow, dodder keeps pace, spreading and branching extensively. Soon the dodder in a field may be detected by the dense growth of yellow, tangled stems, or by the presence of patches of stunted alfalfa plants, and in severe cases, by a mat of dodder and alfalfa. The dodder plant sends small absorbing organs into the tissue of the host, and takes foods from it.

Diseases Due to Adverse Environmental Conditions.—It is well known that hail will injure plants. Too much "alkali" in the soil may also cause serious injury to plants. Plants vary

considerably in their ability to withstand "alkali." The sugar beet, for example, can withstand much more alkali than corn or wheat or potatoes. Blueberries flourish in an acid soil, but become sick and die under other conditions. In certain parts of the irrigated sections of the West, nitrates have accumulated in the soil in such large quantities as to injure the vegetation and make it impossible to grow crops profitably upon them. This injury to plants is called "niter" injury. The accumulation of "niter" in the soil gives it a chocolate-brown color, and the accumulation is the result of soil conditions which favor the very great activity of certain nitrogen-fixing bacteria.

Too much water or too little water in the soil will cause the plants to be sickly, and to be seriously reduced in their growth. "Tip burn" of lettuce is thought to be due to a fluctuation in the temperature and moisture supply, particularly in the presence of readily available potassium and nitrogen. Intense light may cause sunscorch, "bronzing," or sunscald. On the other hand, dense shade may cause plants to become weakly; for example, lawn grass in deep shade may languish and die. The injury of potato and cotton plants by lightning has been reported. In the neighborhood of cities where there is much smoke and fumes from manufacturing establishments, plants are injured; sulphur dioxide and other gases act as toxins. It is known that shade trees are harmed by small quantities of illuminating gases which may escape in the soil from leaking pipes.

There are plant diseases which can not be ascribed to any of of the above causes, which are usually considered to be due to disturbances in plant nutrition. The causes of such diseases are often hard to determine. Any marked deficiency in one or more of the chemical elements essential to growth will result in an unhealthy development of the plant. The "pale" color of plants, a disease known as **chlorosis,** may be due to a deficiency or unavailability of either magnesium or iron, both of which are essential to the formation of chlorophyll. "Die-back" of lemons has been ascribed to the poor nitrifying power of the soil.

Diseases Caused by Insects.—So many of our crop plants are infected with insects, that we are almost forced to the conclusion

that there is not one without its insect enemy. These small animals live upon the juices of the plant, and steal the nourishment which is needed to make the plant grow well. Some of the principal insect enemies of crops are grasshoppers, cut worms, chinch bugs, alfalfa weevil, plant lice, web worms, woolly aphis, codling moth, scales, mites, borers and leaf rollers.

The Principles of Disease Control.—In the preceding pages we have discussed the various causes of diseases in plants. Let us briefly outline the principles of disease control.

Determination of the Cause.—Of course, the first step in the control of a particular disease is to determine its exact cause. This may be difficult, at times, but a line of successful action can not be followed unless the cause is first ascertained.

Knowledge of the Life History.—If the diseased condition is due to an organism, it is essential to know its life history, so that the organism can be attacked at its most vulnerable period. For example, in those smuts, such as bunt of wheat, which infect the host only in the seedling stage, a knowledge of the mode of infection has led to a method of control which involves the destruction of spores on the seed and in the soil about the seed. Again, a knowledge of the life history of black stem rust of wheat has led to the eradication of the common barberry.

Cultural Methods.—It is becoming well recognized that many plants succumb to diseases because of a weakened condition brought about by poor cultural practices. A poorly nourished and weak plant, like a poorly nourished and weak animal, is more subject to the attacks of fungi than are strong vigorous plants. Hence, plants that are well cared for, that have ample water and mineral nutrients, and favorable soil, light and temperaature conditions, such that growth is uninterrupted, have greater powers of throwing off diseases than plants which suffer from a lack of these factors.

Crop Rotation.—Our different crop plants have fungous diseases peculiar to them. For example, corn smut is known only on one common host, and that is maize. The smut spores survive in the soil and may infect the succeeding crop. By growing corn continuously on a given area, there is an accumulation of spores

and an increasing chance for infection. However, if the area is planted to a crop other than corn, the spores lose their vitality or germinate after a time. Then, corn may be planted again in the area without fear of infection from the soil.

Consider another example: potato scab. It has been demonstrated experimentally that the fungus may persist in the soil for several years. Continuous cropping to potatoes only increases the soil infestation. But, if a crop not subject to the attacks of the organism is grown on the infested soil, potatoes may be grown there again.

Disease-free Seed.—In Chapter XII we discussed seeds as carriers of disease. Great emphasis in the control of potato disease has been placed upon the necessity of using disease-free tubers ("seed"). Scab, Rhizoctonia, mosaic, dry rot, late blight and other potato diseases may be carried into the soil by the tubers. Corn kernels may carry on the inside one or more disease-forming fungi. A number of the smuts are seed borne. Anthracnose of beans is carried over from crop to crop largely in the seeds.

Two general methods are adopted to secure disease-free seed, as follows: (1) Seed selection, and (2) seed treatment. The reader may refer to Chapter XII for a more extended discussion of this subject.

Disease Resistance.—Much progress in the control of plant diseases has been made through the breeding of disease resistant strains. In fact, this is one of the most hopeful lines of attack in combating plant diseases. Resistance may be due to a structure which prevents entrance of the organism, or to a nutritional condition that does not supply the proper kind of food.

No two plants are alike. They show variation. Not only may they vary in such particulars as height, color, leaf shape, character of fruit, etc., but in resistance to disease, or performance in some other direction.

The wilt disease of cotton at one time threatened the cotton industry in the Southern States. Progress in its control has been due to the development of resistant varieties. Tests have shown that some varieties of cotton are several hundred times more

resistant to the disease than others. Kanred wheat is a variety relatively resistant to black stem rust. Kieffer and McIntosh pears are relatively more resistant to bacterial blight (fire blight) than the Bartlett variety. Early Crawford and Elberta peaches are more resistant to brown rot of stone fruits than are such varieties as Triumph and Alexandra.

FIG. 129.—The difference between disease-resistant seed and unselected seed of cabbage grown on land heavily infected with cabbage yellows. (From Jones, in *Genetics in Plant and Animal Improvement;* after Jones, Walker and Tisdale.)

Sanitation.—This includes destruction or removal of diseased tissues, the burning of refuse, and soil treatment.

Practical control of apple and pear blight, a bacterial disease, is brought about by pruning out infected twigs, and smaller branches, and by scraping off all diseased tissue of the large branches and main trunk. The instruments employed are also sterilized.

In the case of black knot of plums and cherries, the developing knots should be pruned out as soon as they appear in the spring, and thus prevent the spread of spores which would develop on these swollen areas. Several prunings a season may be necessary to remove the diseased tissue.

The large, swollen, smut masses that develop on corn are well known as the source of clouds of spores which are readily blown by the wind and may infect other plants. Stalks affected with smut should be cut out and burned before the spores mature.

Crop residues and refuse often carry a disease from one season to the next. For example, if smutted corn is thrown on the manure heap, the spores may be carried to the field and become a source of infection.

As a measure of control in the case of onion mildew, the tops of diseased plants should be destroyed. If they are left on the land or returned to it in the manure, infestation of the new crop will occur.

The mummied fruits characteristic of the brown rot of stone fruits, should be knocked from the trees, and together with those on the ground, raked together and burned. These mummied fruits are the principal source of infection the following year.

There are many other plant diseases that are effectually controlled or held in check by the destruction of crop residue or refuse.

A number of disease-forming organisms live over in soil, either in the vegetative stage or spore stage. For example, damping off fungi, which are often prevalent in potting beds, in greenhouses, in seedling nurseries, and sometimes even in fields, live from year to year in the soil, attacking the plants in the seedling stage. Fungi in the soil may be destroyed by steam sterilization (Fig. 130) of the soil, and by drenching it with formalin. Club root of cabbage, a disease which attacks a number of cruciferous plants such as cauliflower, turnip, rutabaga, brussels sprouts, radish, and other mustards, may be prevented or checked by applying lime to the soil, at the rate of about 100 bushels per acre.

Application of Fungicides.—The spraying or dusting of plants with chemicals is now a common method of controlling many

fungous diseases. Twenty-five years ago, however, the practice was little used. In the use of most all fungicides the object is to cover the surface of the plant with a chemical which will prevent the germination and growth of spores which may already be on the surface or light on it later. The spore itself may absorb sufficient of the poison on the plant surface to kill it; or when the

FIG. 130.—Sterilizing greenhouse soil by the perforated-pipe method. (From Beattie, in U. S. Dept. Agr. Farmers' Bulletin No. 1320.)

spore germinates, and sends out a slender tube, if there is a poisonous chemical in its path, and this is absorbed, growth is prevented. Thus sprays and dusts are preventives rather than cures.

Of course, the fungicide employed must not be injurious to the host. Fortunately, the thick cuticle which covers the surfaces of twigs, leaves, and fruits usually prevents the absorption of sufficient poison to injure the host, providing the fungicide is properly made.

The common fungicides in use to-day are Bordeaux mixture,

copper sulphate, ammoniacal copper carbonate, lime sulphur, flowers of sulphur, corrosive sublimate, and formalin.

Tree Surgery.—The work of various wood-destroying fungi, and mechanical injuries of different sorts may necessitate special surgical methods to prevent the destruction of trees. The underlying principles in these methods are (1) the removal of all diseased or dead tissue, so as to secure a fresh surface, thus permitting the development of wound cork; (2) the sterilization of the exposed surface; and (3) the covering of the surface with some material which will not allow the entrance of fungi.

If fungi invade the tissue and cause decay, it is necessary to remove some live tissue beyond that which is clearly dead. Common materials used to sterilize and cover the exposed surface are commercial creosote, asphaltum, tar, and Bordeaux paste.

CHAPTER XXIII

MOSSES, FERNS, FERN ALLIES, AND GYMNOSPERMS

The General Character of Mosses.—The name "moss" is applied popularly to a number of different kinds of plants. Some of the seaweeds are called "sea mosses," but the true mosses never occur in saline waters. The "Spanish moss" (*Tillandsia*) which hangs from the trees in our southern swamps is not a true moss but a flowering plant. "Reindeer moss" is a lichen, as is also the "moss" that hangs from the limbs of conifers in the northern states and in the high mountains of the West.

The true mosses are low plants seldom more than a few inches in height, with an erect stem, upon which very small leaves are densely crowded. The leaves are usually but one cell in thickness, except along the midrib and sometimes around the margin. There are no true roots in mosses. They possess structures known as **rhizoids,** which although they do not have the structure of roots, serve the same purposes of absorption and anchorage.

A distinctive feature of mosses is the "fruiting" or spore-producing body. This is a **spore-case** or **capsule,** at the tip of a stalk (Fig. 131). Numerous asexual spores are borne within this capsule.

Mosses are found chiefly in moist woods and in swamps, but some species occur on the bark of trees and in dry rock crevices. In regions with a prolonged moist season, they may be seen growing on fences, and on the shingle roofs of old buildings. They are conspicuous on account of the "carpet" or mass of vegetation they form.

The Life History of Mosses.—The mosses are divided into three distinct groups: (1) The peat mosses, (2) the black mosses, and (3) the true mosses. They differ somewhat in their appear-

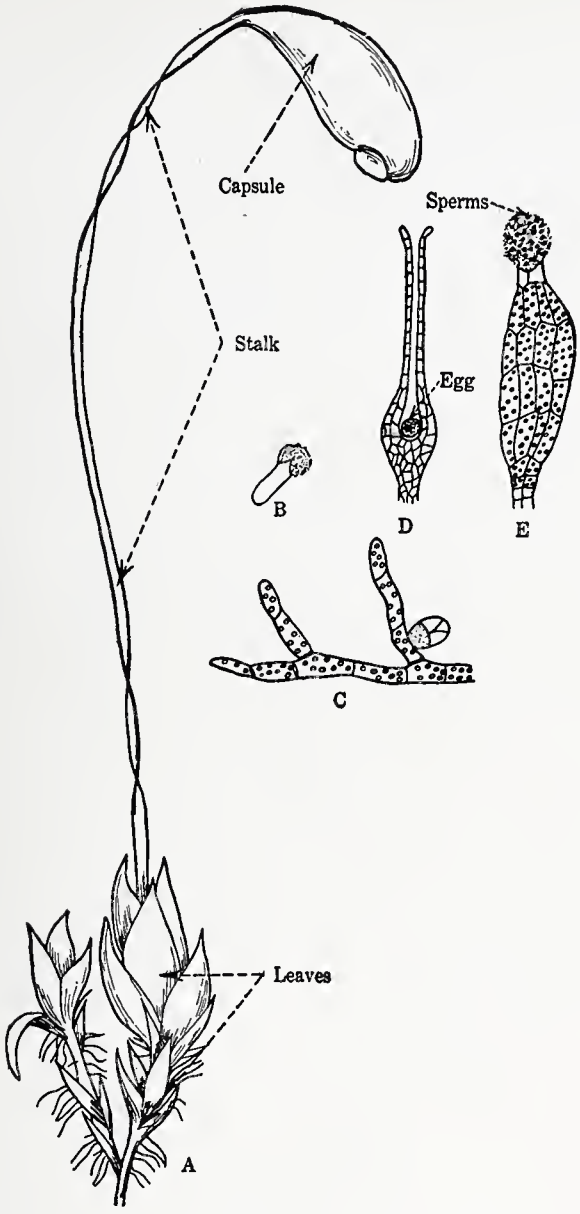

FIG. 131.—Moss. *A*, portion of leafy moss plant and spore-bearing structure; *B*, single spore showing germ tube; *C*, algal growth which develops from germinating spore; *D*, female sex organ; *E*, male sex organ. (From Holman and Robbins, in *A Textbook of General Botany*.)

ance, structure, habits and life history. The following is the life history of one of the true mosses, which are the best known: Numerous one-celled spores are borne in the spore case (Fig. 131). The spores, falling upon moist earth, germinate and each forms a single row of cells attached end to end. In greenhouses this stage may form a conspicuous green coating over the surface of the soil, which resembles the growth of algae. By vegetative multiplication, certain cells develop into stems and leaves, and the adult moss plant is formed. The moss plant bears the male and female sex organs. These may be borne on the same or on separate plants. The sex organs are very small, in fact, microscopic, and lie imbedded in the tip of stems, and surrounded by leaves. By stripping the stem of leaves and cutting lengthwise sections down through the tip, the sex organs may be seen with the aid of the microscope. The female sex organ is a flask-shaped body (Fig. 131, D). It has a **basal portion** which contains the single **egg,** and a long **neck.** The male sex organ (Fig. 131, E) is a globe-shaped or somewhat elongated capsule which produces numerous sperms. The sperms are discharged from the male sex organ, and by swimming in the water, some of them find their way to the neck of the female sex organ. Numerous sperms may pass down the central canal of the neck, but only one succeeds in entering the egg and effecting its fertilization. The fertilized egg by repeated cell division develops a long stalk and capsule which remains attached to and dependent upon the moss plant for mechanical support and nourishment.

Economic Uses of Mosses.—Surely, one would not overlook the value of mosses in enhancing the beauty of our natural scenery. But some of them find commercial use. Sphagnum moss was used extensively in the recent war in surgical dressings. The American Red Cross alone turned out half a million sphagnum dressings for the Italian army, and about twenty thousand a month for American war hospitals. Sphagnum surgical dressings are in many respects superior to absorbent cotton. Sphagnum absorbs liquids about three times as fast as absorbent cotton, and it holds more than three times as much water as cotton; it retains liquids better than cotton and continues to absorb them until it

is quite uniformly saturated throughout; and, again, sphagnum is cheaper than cotton.

The efficiency of sphagnum moss as an absorbent is due to its peculiar structure. Whereas, ordinary moss leaves possess just one sort of cell as shown in Fig. 132, the leaves of sphagnum

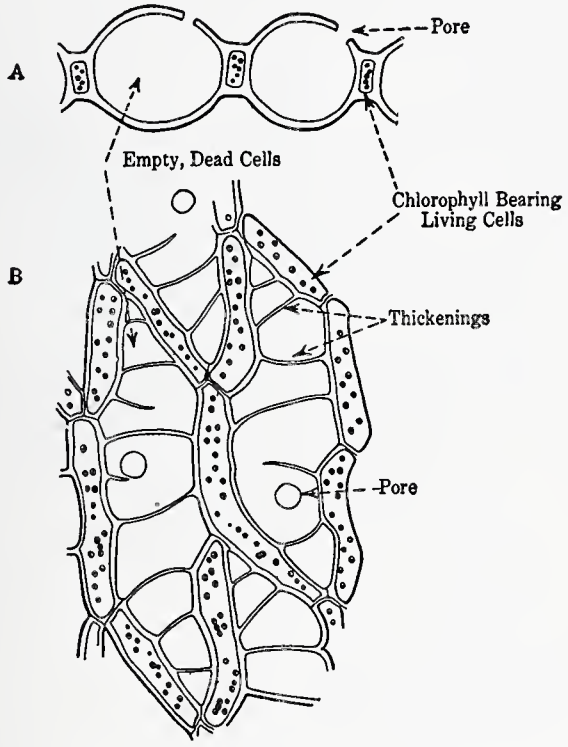

FIG. 132.—Sphagnum moss. *A*, a portion of leaf in cross-section; *B*, portion of leaf in surface view. (From Holman and Robbins, in *A Textbook of General Botany.*)

have two kinds of cells. There are (1) long, chlorophyll-bearing cells, and (2) large water-storage cells. The walls of the large cells are often perforated by round pores. These cells are capable of absorbing and retaining large amounts of water.

The sphagnums or peat mosses are important for another reason. In the British Isles, particularly, peat is a chief fuel supply. There are many million cubic feet of peat in the north-

ern tier of states, but up to this time it has been little used on account of cheaper and more satisfactory fuels.

Sphagnum moss is used extensively as a packing for plants in shipment. For example, in the shipping of fresh asparagus, the bunches are stood on moist moss.

Fig. 133.—Portion of the rootstock and leaves of the Christmas fern. Note the young coiled leaves and expanded leaves. (After Curtis.)

Ferns and Their Allies.—The ferns and their close relatives, the club mosses and scouring rushes (horsetails), constitute a large group of plants. Like the algae, fungi and mosses, they reproduce by means of spores, but unlike these groups, they possess woody stems and roots, and a conducting tissue, similar to

that in flowering plants. The ferns and their allies do not produce flowers.

In the common cultivated ferns, the stem system is wholly under ground (Fig. 133). It persists from year to year, growing in length at the tip, branching somewhat, and sending into the air each season a number of leaves, the so-called **fronds.** After a time, there appear on the under side of the frond brownish groups of spores which are often mistaken for some disease or insect. They

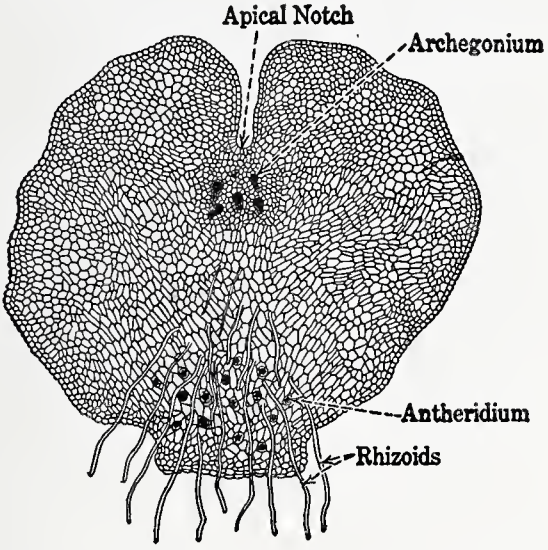

FIG. 134.—A stage in the life history of a fern. Under side of small, green heart-shaped body which gives rise to female sex organs (archegonia) and male sex organs (antheridia). The rhizoids are root-like structures which serve both for absorption and anchorage. (From Holman and Robbins, in *A Textbook of General Botany.*)

are, however, the reproductive bodies. The spores are shed, blown by the wind, and germinate on moist soil. The germinating spore gives rise to a very small, flat, green, heart-shaped structure about $\frac{1}{8}$ to $\frac{1}{4}$ of an inch in diameter (Fig. 134). These may frequently be seen on the moist soil beneath fern leaves. They bear the sex organs. Following fertilization of the egg in the female sex organ, the ordinary fern plant develops.

In propagating ferns, the common practice is to divide the

rootstock. It is very difficult to grow fern plants from the spores, the progress being so slow and uncertain as to make the practice impracticable.

The **horsetails** or **scouring rushes** (Fig. 135) have harsh, jointed stems which arise from a rootstock. The leaves are mere scales. The spores are borne in a cone at the tip of certain branches.

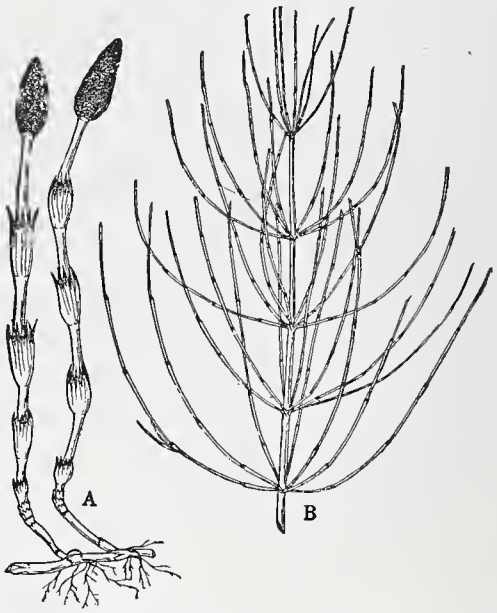

FIG. 135.—Horsetail or scouring rush. *A*, early spring stems arising from rootstock; note the scale-like leaves at the joints and the spore-bearing cones at the tip; *B*, branching form which appears later in the season than the preceding. (From Glover and Robbins, in Colo. Agr. Exp. Station Bulletin.)

On account of their harsh texture, the plants have been used for cleaning and polishing utensils. They are reputed to be poisonous to livestock, chiefly horses. Sometimes they behave as weeds.

The **club mosses** are usually creeping or trailing plants, sometimes known as "ground pine" or "running cypress." The spores are borne in leafy cones at the tips of branches. The spores are sold in drug stores under the name "lycopodium powder," and are used as a drying powder and to some extent in the manufacture of fireworks.

The Gymnosperms.—The gymnosperms include such well-known plants as the conifers, among which are the pines, spruces, firs, cedars, hemlocks, arbor-vitae, and redwood. The mention of these names is sufficient to show how important the group is commercially. It is a source of lumber, rosin and turpentine.

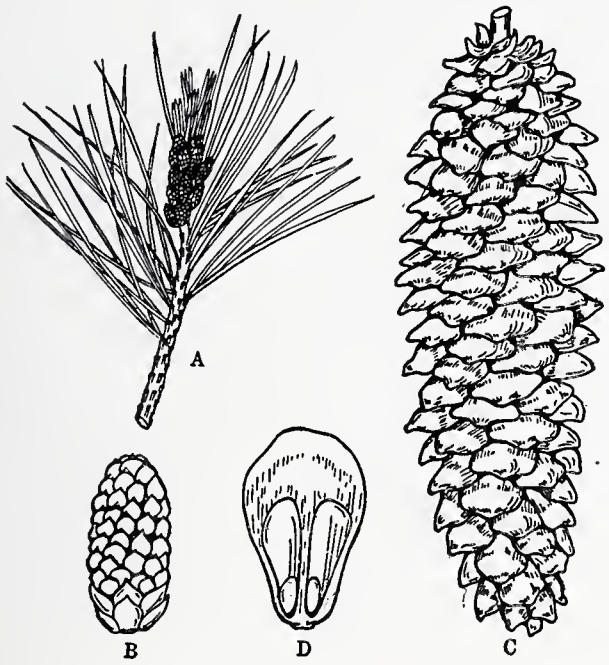

FIG. 136.—Sugar pine. *A*, twig showing needles (leaves) and cluster of staminate cones; *B*, a single staminate cone; the scales are papery; *C*, a single pistillate cone; the scales are woody; *D*, a scale from pistillate cone with the two winged seeds attached. (Redrawn from Holman and Robbins, in *A Textbook of General Botany.*)

Fully 70 per cent of the timber cut each year in the United States is furnished by coniferous species.

Gymnosperms are **seed plants,** but they do not bear flowers of the kind with which we are most familiar. The seeds are borne on the surface of scales, which are grouped together, forming a **cone** (Fig. 136, C), which is often woody. The stamens are also grouped into cones which are much smaller, more papery, and shorter-lived than seed-bearing cones. Thus, there are two kinds

of cones in our common gymnosperms: woody, **seed-bearing** or female cones, and papery, **pollen-bearing** or male cones.

In all flowering plants, such as wheat, beans, cabbage, apple, plum, watermelon, etc., the seeds are borne in a case (the ovary), and are surrounded by several layers of either dry or watery tissue. In gymnosperms, on the other hand, the seeds are not enclosed in a case, but exposed on the surface of the scale to which they are attached. The seeds are often provided with a wing, by which they may be carried by the wind (Fig. 136, D).

The quantity of pollen produced by pines, and other conifers, is enormous. The pollen is yellow in color and has the appearance of " flowers of sulphur." It is spread wholly by wind, being carried for hundreds of miles.

The wood of conifers is distinctive in that it is devoid of long tubes which conduct water. This function of conduction is performed by relatively short, thick-walled cells, which also give strength to the stem.

The leaves of most conifers are needle-shaped and evergreen. Any one leaf remains on the tree from two to ten years. A plant with evergreen foliage is subject to water loss the entire year.

Conifers are propagated by seeds, by cuttings and by grafts. Cuttings are usually from one-year-old growth with a two-year heel. In grafting, the scion is attached to the stock as near the root as possible.

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(An asterisk (*) indicates an illustration)

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